RESULTS REPORT:

FACILITY LIGHTING — WINTER

WAYNE N. ASPINALL FEDERAL BUILDING

GRAND JUNCTION, COLORADO

Submitted to:

U.S. General Services Administration

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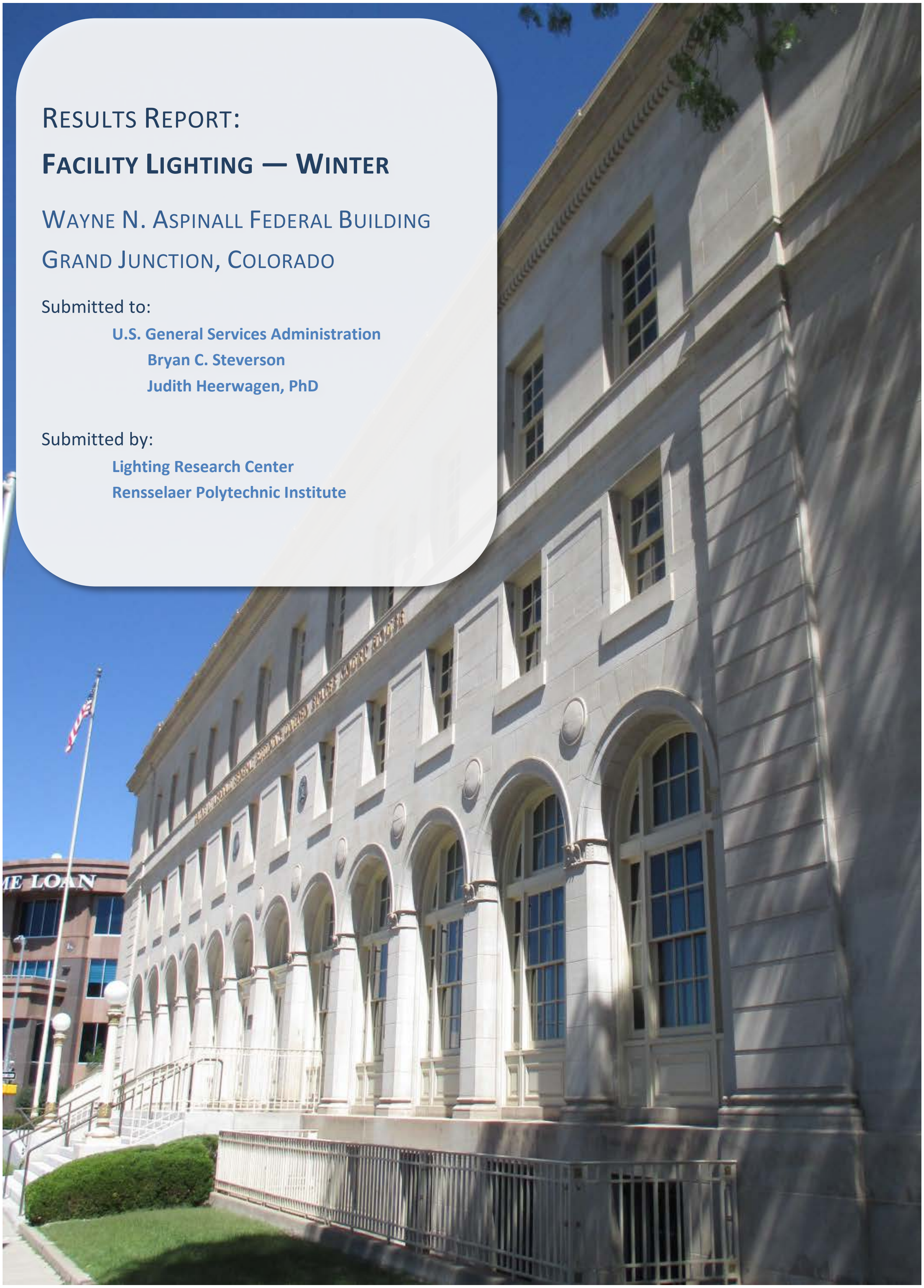

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Wayne N. Aspinall Federal Building, Grand Junction, Colorado

Submitted March 11, 2014

V2: revised/updated May 18, 2016

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Executive Summary

On January 6-7, 2014, a researcher from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute performed a site evaluation at the Wayne N. Aspinall Federal Building in Grand Junction, Colorado. The goal was to measure photometric conditions as they relate to occupant comfort, productivity, and circadian health.

The Wayne N. Aspinall Federal Building is a three-story, Second Renaissance Revival style building constructed in 1918, managed by the U.S. General Services Administration (GSA). It was the first permanent post office building constructed in Grand Junction. Recently, it was completely renovated with the goal of converting the building into one of the most energy-efficient and sustainable buildings in the country.

During the evaluation, the LRC found that on the north and west sides of the building, illuminance measurements at the second row of desks were consistently lower than the first row of desks. In addition, one row of desks on the north side had no overhead lighting, and thus, very low light levels (4-19 footcandles [fc]) compared with 30-60 fc on the desks closer to the west windows. Since industry recommendations range 30-50 fc, light levels at the second row of desks may produce occupant complaints. Exposure to low light levels during the day may also result in circadian disruption. However, most of these desks were vacant. The light levels may need to be increased if staffing expands to full occupancy in the future.

The LRC also found some issues with photosensor dimming functionality. On the north and west sides of the first floor, the photosensor dimming system appears to aggressively step down light output to about 25% of full light output on sunny days, which in this evaluation, resulted in lower light levels than after dark. Output does not appear to be continuously variable throughout the day, but instead appears to step down abruptly and stay low throughout the day until late afternoon when it steps up again abruptly. The controls system may need to be adjusted so that the illuminance on the desk is not permitted to drop lower than the intended design illuminance (i.e., nighttime at full output). Dimming might also be less noticeable if it occurred continuously, rather than abruptly.

During winter, luminaires in south-facing offices do not appear to be dimming in response to sunny weather. These spaces use shades extensively so the photosensor mounted indoors may not be "seeing" enough light to trigger dimming of the lights. Arguably, this is a good strategy to prevent desk spaces from becoming too dim. However, this means that the investment in photosensors and dimming equipment for south-facing offices is not being put to use in winter. Occupants use shades if available; however, they do not typically retract shades when cloudy, which may cause photosensors to keep electric lights at full output. Since the photosensors are indoors and are affected by shading, some energy savings could be achieved on cloudy days if staff were encouraged to open the window shades.

The LRC administered questionnaires to 16 people working in the building. Most respondents indicated they have enough light for work; some (38%) think there is slightly too little light. About half the respondents think the luminaires and the windows are comfortable to look at, while the remaining responses indicated that glare was an issue.

For this site evaluation, LRC researchers installed four Daysimeters in vacant office spaces. Daysimeters were also worn for seven consecutive days by 11 employees (results from the Daysimeters worn by workers is submitted in a separate report). Light levels from the four Daysimeters installed in offices showed that, in the second row (far from windows), the amount of light that is considered effective for activating the circadian system (circadian stimulus) is in the lower range. The only measurement that showed a significant amount of circadian stimulus was when the device was placed on top of a file cabinet, suggesting that, even though partitions provide the worker with some privacy, they also reduce access to daylight. As a next step, the LRC will compare the measurements obtained with the Daysimeters installed in offices to those obtained with the devices worn by workers.

Overview

On January 6-7, 2014, Lighting Research Center (LRC) researcher Jennifer Brons performed a site evaluation at the Wayne N. Aspinall Federal Building in Grand Junction, Colorado. The LRC conducted photometric measurements in the facility during winter 2014, and will repeat the measurements in summer months. For the site evaluation, Ms. Brons was met by the onsite property manager, Tim Gasperini, as well as architect Jason Sielcken. The goal of the research was to measure photometric conditions as they relate to occupant comfort, productivity, and circadian health.

The Wayne N. Aspinall Federal Building is a three-story Second Renaissance Revival style building constructed in 1918, managed by the U.S. General Services Administration (GSA). It was the first permanent post office building constructed in Grand Junction. Recently, it was completely renovated with the goal of converting the building into one of the most energy efficient and sustainable buildings in the country. Some of the awards received after the renovation include:

- LEED Platinum
- Design Build Institute of America – Rocky Mountain Region Award for the Best Project in the category of Rehabilitation/Renovation/Restoration
- AIA Colorado – Honor Award for Built Architecture
- AGC Colorado – Award for Construction Excellence (ACE)

Reported here is the first set of photometric measurements performed during winter months.

Methods

Photometric Measurements

The LRC measured horizontal and vertical illuminance[1] as well as window luminance[2] at 15 desk locations; see Figures 1 and 3. Measurements were repeated at these locations throughout the day, approximately 2 hours apart. These locations were chosen to represent the variability in indoor lighting conditions.

The weather on the setup day (1/6/14) was sunny, typical of Grand Junction. However, the weather on the primary measurement day (1/7/14) was mostly overcast. In order to provide some comparison to typical Grand Junction weather, the LRC added 2-3 cycles of measurements on the sunny day.

[1] A measure of light landing on a surface. As illuminance is a measure of flux density (lumens per area), illuminance can be reported in English units of footcandles (fc), or SI units of lux (lx). 10.76 lx = 1.0 fc

[2] A measure of light emitted or reflected by a surface. Units are candelas per square meter.

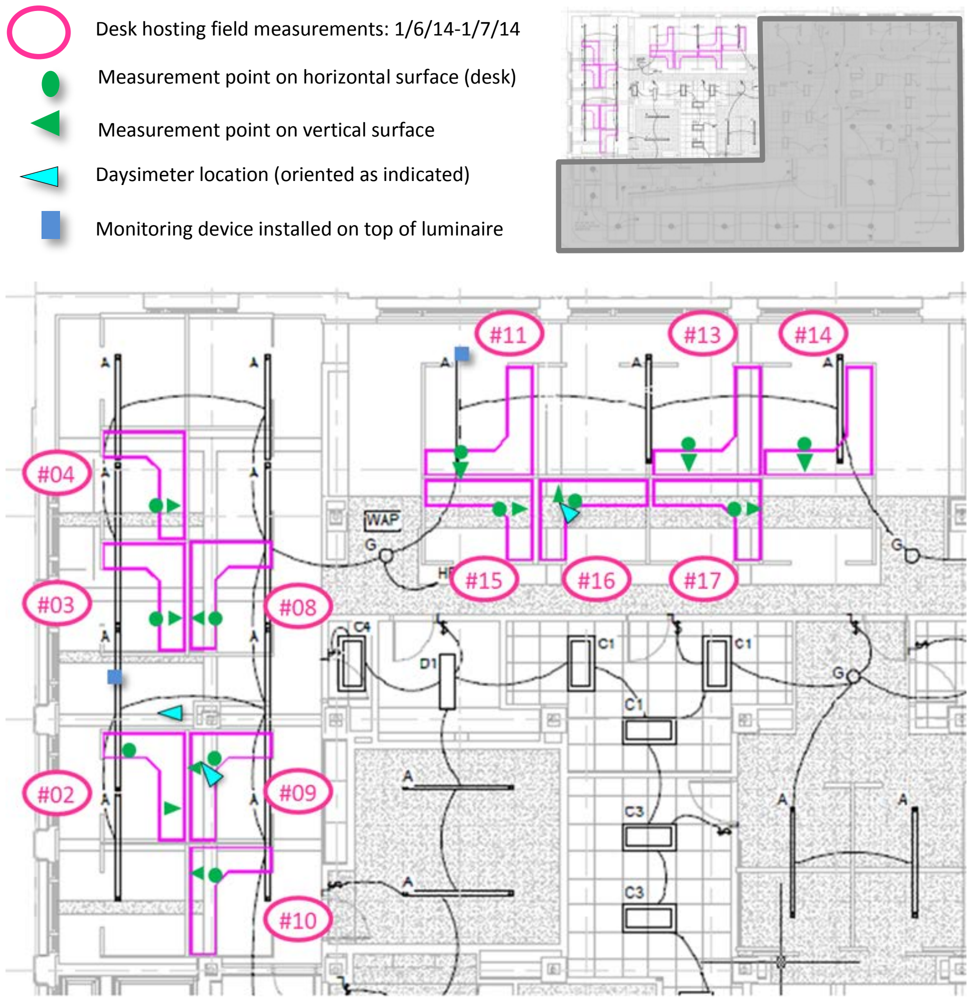


Figure 1. First floor measurement locations: north and west orientations.

Electric lighting consists of linear fluorescent luminaires that hang below the ceiling and shine light both upward and downward ("pendants"). According to Mr. Sielcken, the rows of lights closest to the windows are intended to dim in response to daylight. According to project documentation, photosensors mounted on the ceiling command the window luminaires to dim when illuminance at the ceiling exceeds the setpoint.[3] Photosensor locations are shown in Appendix D.

Window shades were not in use on the north-facing windows on the first floor. Several of the west-facing windows did have black mesh shades pulled down, as shown in Figure 2.

[3] Mr. Sielcken can provide details about commissioning set points, equipment model numbers; the LRC does not have this information. As-built lighting control plans are shown in Appendix D.

Figure 2. West-facing windows are fitted with black mesh shades.

As shown below, three desks were used for measurement of the south building exposure.

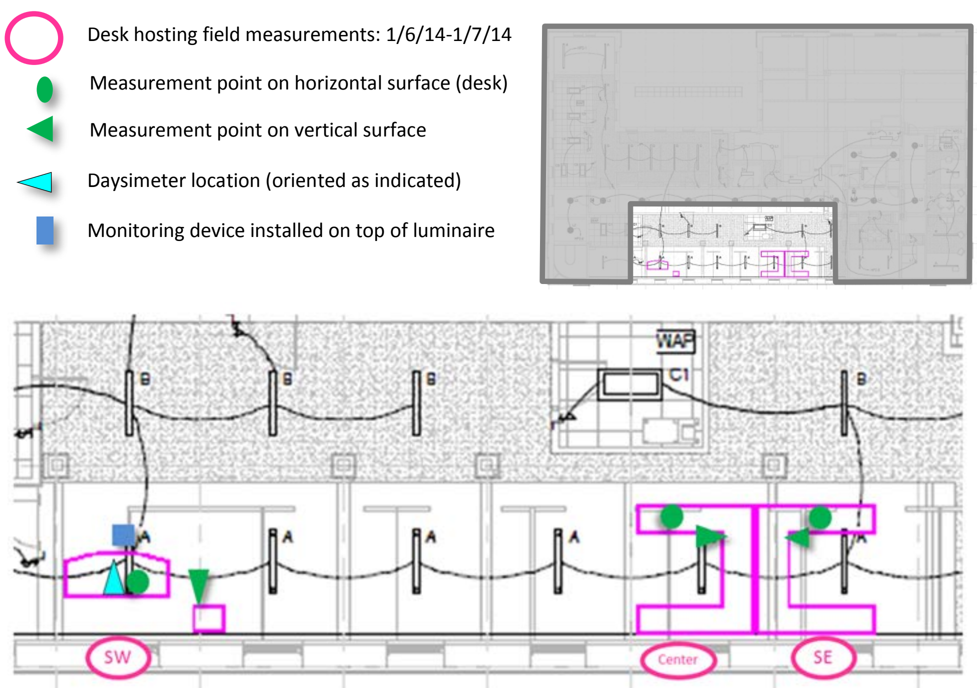


Figure 3. Second floor measurement locations: south orientation.

For these south-facing windows, personnel have the option of using the (translucent) black mesh shades, as well as opaque blackout shades (Figure 4). Electric lighting appears to be the same fluorescent pendants as on the first floor. As shown in Appendix D, one sensor sends a signal to all the luminaires in the space; although the right window in Figure 4b has blackout shades retracted, subsequent sun may not be “seen” by the sensor.

ONGOING LIGHT MONITORING WITH DAYSIMETERS

The LRC installed four Daysimeters in vacant office spaces; see Figures 1 and 3 for locations. Personnel onsite retrieved these devices after about two weeks of data collection in January 2014. Daysimeters were used to measure continuous light exposures close to eye levels of those who would be using the desk space, if it were to be occupied.

Figure 4. (A) A close-up of the translucent black mesh shades personnel with south-facing windows have the option to use. (B) Although one window has blackout shades retracted, the sun may not be "seen" by the photosensors in the room.

Daysimeters were also worn for seven consecutive days by 11 employees and results of this part of the study will be submitted in a separate report. The physical characteristics of the Daysimeter and its calibration have been previously documented (Figueiro et al. 2013). The goal of collecting personal light exposures from employees is related to the effects of light on circadian rhythms. Biological rhythms that repeat approximately every 24 hours are called circadian rhythms. Light is the main stimulus that helps the circadian clock, and thus circadian rhythms, to synchronize with the 24-hour day. In other words, light tells our body to stay awake during the day and to sleep at night, so that our sleep-wake cycle mirrors the earth's 24-hour cycle of night and day. Light of the appropriate quantity, spectrum, timing, duration, and distribution can have a profound effect on sleep, alertness, and performance, along with overall wellbeing. Circadian disruption has been associated with health risks, including diabetes, obesity, cardiovascular disease, and cancer.

Lighting characteristics affecting our circadian clock are different than those affecting our visual system. In brief, we need at least 10 times more light to activate our circadian system than to see. Light levels used in offices [e.g., 500 lux (approx. 50 fc) on the work plane; about 100-200 lux (approx. 10-20 fc) at the cornea] are sufficient for one to read black fonts on white paper, but only slightly affect the biological clock. The biological clock is especially sensitive to blue light (460 nm). The biological clock cares about exposure to light over the course of the 24-hour day. Morning light will help us go to bed earlier and wake up earlier while evening light will help us go to bed later and wake up later. Therefore, it is important to measure light that affects the circadian system using a calibrated device, and more importantly, being able to know when a person is exposed to circadian light over the course of the 24-hour period. The Daysimeter serves this purpose.

As part of the site evaluation, the LRC used Daysimeters to collect seven days of continuous light/dark and activity rest data from employees. These data allow the LRC to determine whether the employees are getting enough circadian stimulation during the daytime in the building. As mentioned above, light of the appropriate quantity, spectrum, timing, duration, and distribution can help to maintain a healthy sleep-wake cycle (restful sleep at night, alertness during the day) and avoid health risks associated with circadian disruption (e.g., diabetes, obesity, cardiovascular disease, cancer, etc.).

Briefly, light sensing by the Daysimeter is performed with an integrated circuit (IC) sensor array (Hamamatsu model S11059-78HT) that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR). The R, G, B, and IR photo-elements have peak spectral responses at 615 nanometers (nm), 530 nm, 460 nm, and 855 nm, respectively. The Daysimeter is calibrated in terms of orthodox photopic illuminance (lux) and of circadian illuminance (CL_A). CL_A calibration is based upon the spectral sensitivity of the human circadian system. From the recorded CL_A values it is then possible to determine the circadian stimulus (CS) magnitude, which represents the input-output operating characteristics of the human circadian system from threshold to saturation. These measurements will be more meaningful for determining personal light exposure when data from the devices worn by the users of the building is analyzed, but the static measures are reported here for reference purposes.

These static measurements from Daysimeters installed in office spaces (Figure 5) are representative of light exposures received while sitting at the desk working at a computer. However, these measurements may not represent the person's daily light exposures, such as exposure to outdoor lighting to and from work. The Daysimeter worn by the study participants for seven days will be able to detect the amount of outdoor light the participants receive. The Daysimeter is also able to continuously measure rest/activity pattern with three, orthogonally oriented, solid-state accelerometers that are calibrated in terms of gravitational forces on the device.

Figure 5. (A, left) A Daysimeter measures circadian light exposure. (B, right) Daylight comes in through an office window.

RESULTS

PHOTOMETRIC MEASUREMENT RESULTS

In the first floor spaces, measurements before 8 a.m. are assumed to have little or no daylight.[4]

SOUTH-FACING WINDOWS.

Employees with south-facing windows tend to use shades. At many desks, illuminance measurements did not vary substantially between the sunny day and the cloudy day. Because measurements were similar after dark, early in the morning, and throughout the day, it is assumed that there was little contribution from daylight at the measurement points shown above for this southern exposure. Data from other devices indicate that during this monitoring period, the lights in this space were not dimming in response to daylight. It is possible that the use of shades not only limited illuminances at the desks, but also at the photosensor on the ceiling, which may explain why it did not dim down the lights.

As shown in Appendix A and Figure 6 below, illuminances on the desk (horizontal) at these measurement points were around 400 lux (40 fc); vertical illuminances were around 200 lux (20 fc). The person working at the center desk chose to open his blackout shades on the overcast day (1/7/14), thus measurements at his desk were higher than at the southeast (SE) desk. The southwest (SW) desk was vacant, so only mesh shades were used, not blackout shades.

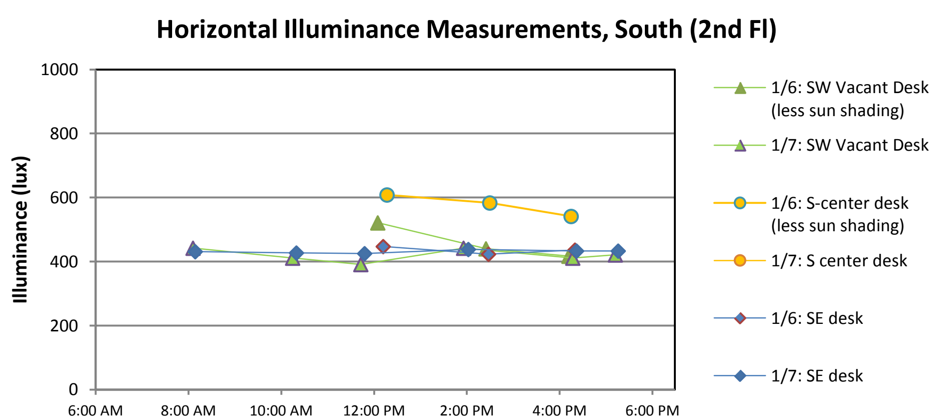


Figure 6. Horizontal illuminance measurements on the southern exposure (second floor).

The occupant at the SE desk pointed out that the mesh shades in the second floor south windows are not long enough to fully cover the window. In the summer, the sun is high in the sky and does not fall on the desk surface. But in the winter, the occupant uses office supplies to cleverly shield the sun; see Figure 7. The adjacent (center) office did

4 Due to the nature of the government work taking place in this first floor space, the LRC was not permitted to make unattended measurements at night, when the office was closed. As a result, the early morning measurements (at 7:45 a.m.) are assumed to represent electric-only data. Also, the LRC was not permitted to turn lights on and off to repeatedly measure daylight with and without electric light.

not employ this shading technique, thus showed higher illuminances even on the sunny day when the blackout shade was down.

Figure 7. (A, left) As the mesh shades on this second floor south window are not long enough to fully cover the window, the occupant of this desk uses office supplies to shield the sun in the winter. (B, right) The sun hits the desk through the gap between the shade and window when the window is not covered.

NORTH-FACING WINDOWS

As shown in Appendix B and Figure 8 below, for the first row of desks on the north side of the building on the first floor, illuminances on the desk (horizontal) were lower on the sunny afternoon (e.g., 125-245 lux on 1/6/14) than on the cloudy afternoon (e.g., 304-680 lux on 1/7/14). Other data (see page 14) indicate that the electric lights were operating at low output on the sunny day, and were at full output on the cloudy measurement day. The lighting control system may need to be adjusted so that light levels on the desks are not lower on sunny days than cloudy days or after dark (target illuminance was not listed in the documentation). Typically target illuminance would be between 30-50 fc (300-500 lux on the work plane). The minimum amount of light during the day should be no less than the electric light only after dark. In general, given that this is a daylit space, the amount of light during the day is not likely to be lower than at night. However, reducing the aggressiveness of dimming will translate to less energy savings.

Cubicles on the first floor are fitted with linear fluorescent task lights. One person on this north side uses task lights, thus higher vertical illuminances were observed compared to other colleagues in the first row. This person also uses a task light fitted with a 60W incandescent neodymium lamp.

On the north second row desks, horizontal illuminances were low [40-220 lux (4-20 fc)] throughout the measurement day. It should be noted that these second row desks do not have electric lighting overhead due to a large skylight that does not receive direct sun due to its location behind the protruding second and third floors. Vertical illuminances were equivalently low [30-170 lux (3-16 fc)]. If these desks eventually become occupied, task lighting will be necessary and energy use will increase (though not necessarily to a substantial extent).

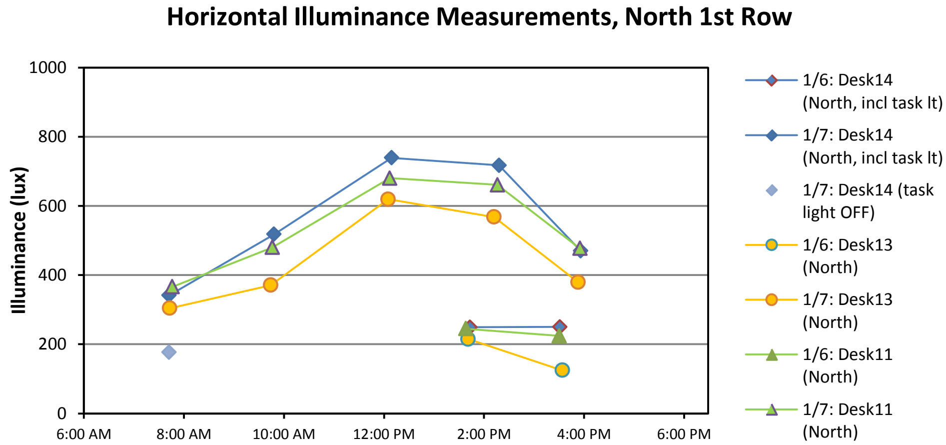


Figure 8. Horizontal illuminance measurements on the north desks, first row.

West-Facing Windows

As shown in Appendix C and Figure 9 below, on the first row of the west side, horizontal illuminances started at about 400-550 lux in the morning (not including contribution from a task light). Keeping mesh shades open and use of task lights increased both horizontal and vertical illuminances. One desk had shades open, and the two others had shades closed. On the sunny afternoon, horizontal illuminances were actually about half the values of the cloudy afternoon. This may be due to the fact that the overhead lighting was dimmed to low output on the sunny day, but was operated at full output on the cloudy day (see page 6). As discussed above, the lighting control system may need to be adjusted to be less aggressive, which would translate to less energy savings.

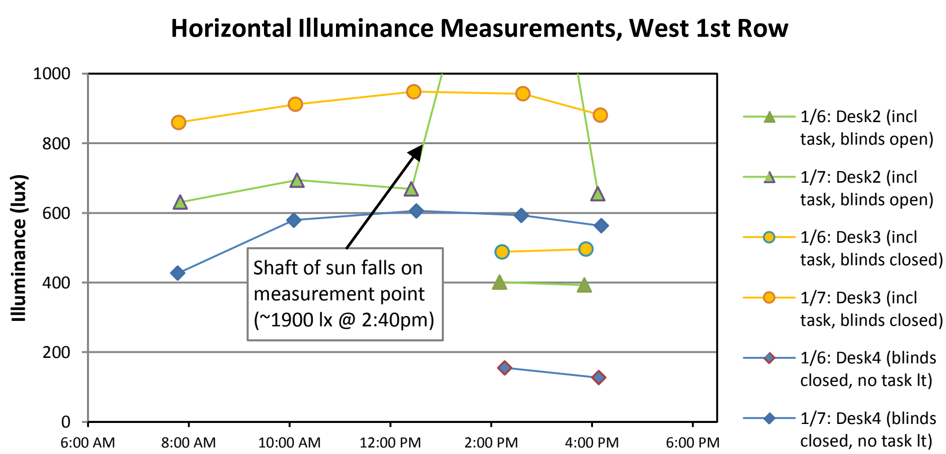


Figure 9. Horizontal illuminance measurements in the west, first row of desks.

In the second row of the west side, horizontal illuminances were about 450-550 lux throughout the day at all three desks. Measurements on the sunny day were lower than the cloudy day for both horizontal and vertical measurements. As this space has tall ceilings (greater than 12 ft.), these desks may be receiving light from the row of lights close to the windows, which are aggressively dimming in response to daylight.

Alternatively, the second row of lights (directly above this row of desks) may possibly be included in the lighting control zone closest to the west windows, and may be dimming in response to daylight; if so, these lights should be removed from photosensor operation.

Luminance Measurements

The LRC used a luminance meter to measure the amount of light emitted by bright surfaces such as windows. While there are no industry-recommended limits on luminances, higher luminance values may contribute to increased ratings of glare. LRC researchers measured luminance at one viewing position per desk, based on the desk's closest view of a window, and brightest patch on the first measurement afternoon. Measurements were repeated for the same viewing location despite the possibility that at different times of the day, other areas of the window may have had higher luminances.

South-Facing Windows

As shown in Appendix A and Figure 10 below, luminance measurements from the south desk seating positions show the impact of window treatments and furniture arrangements. When the person at the center desk opened his blackout shades after the 10 a.m. measurement, subsequent luminance measurements were higher than the sunny day despite the cloudy skies; on the sunny day his blackout shades were down, so luminances were lower.

Seating orientation also affects view of potentially glaring windows. The vacant desk is facing away from the window, while the seats at the center and SE desks are oriented perpendicular to the window. Furniture placement is an important consideration when it comes to maximizing light on the desk and minimizing direct or reflected glare. LRC recommends placing computer screens perpendicular to windows to minimize glaring reflected images from windows in shiny surfaces such as computer monitors ("veiling reflections"). Veiling reflections undermine the user's ability to see their work on the computer monitor.

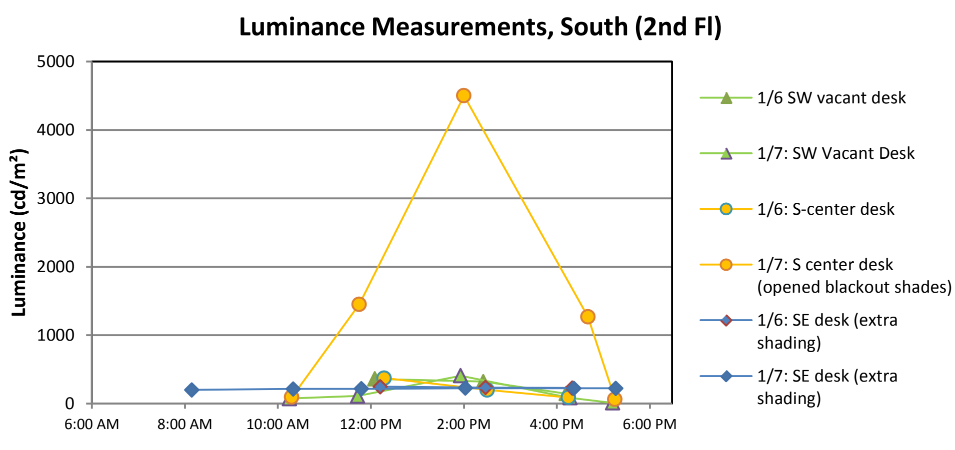


Figure 10. Luminance measurements on the south desks, second floor.

North-Facing Windows

For windows on the north side of the building, there are no window treatments. This is common since in the northern hemisphere, the sun rarely shines on the north side of buildings, and not during normal business hours. As shown in Appendix B and Figure 11 below, luminances viewed from the north desks (without shades) were higher than those measured at the south desks (with shades). Seats in the first row of the north side face away from the windows and face diagonally towards the window in the second row.

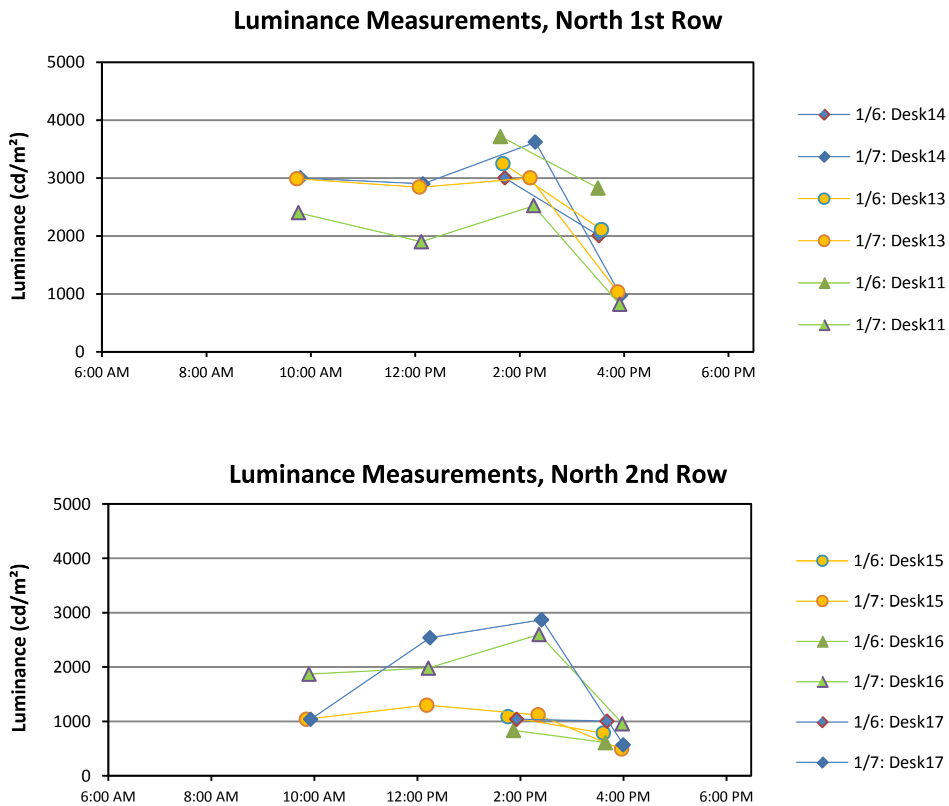
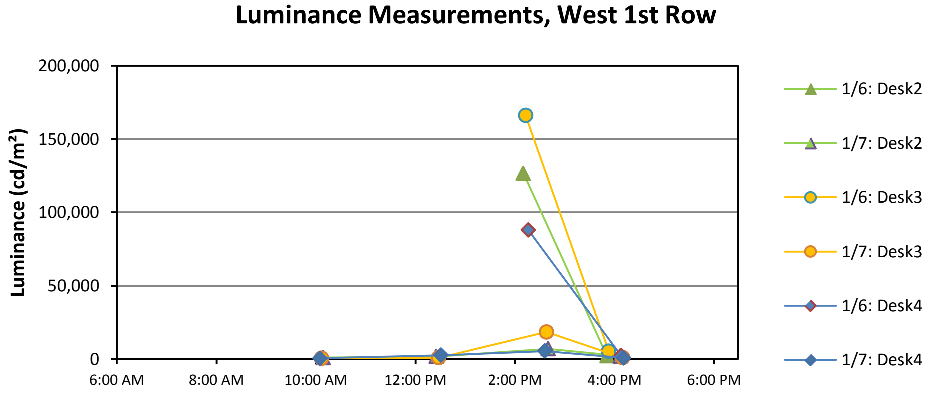


Figure 11. (A, top) Luminance measurements: north desks, first row. (B, bottom) Luminance measurements: north desks, second row.

West-Facing Windows

As shown in Appendix C and Figure 12 below, the desks in the first row on the west side had peak window luminances on the sunny afternoon. Luminance is a photometric measurement that is most closely related to perceived brightness (it is important to note that luminance and brightness are different, but since there are no meters that measure brightness, luminance is used as a surrogate). These occupants work with their backs to the window wall, thus face diagonally northeast rather than west. On the second row of western desks, luminance at 4 p.m. was too high for the meter measure (> 49,990 cd/m²) at Desk 8. Desks 9 and 10 had similar luminances as the south center desk with the blackout shades retracted (around 4000 cd/m²). Desks in the second row face the western window wall, and most of these desks are vacant; no complaints of window glare were registered in the questionnaire.



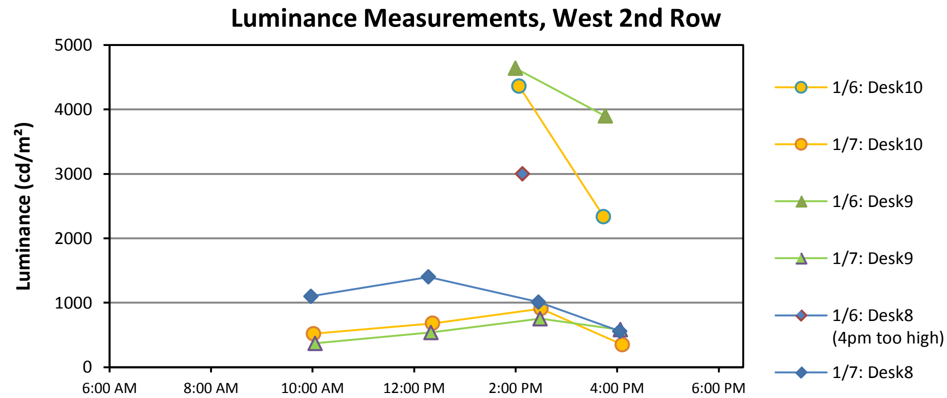


Figure 12. (A, top) Luminance measurements: west desks, first row. (B, bottom) Luminance measurements: west desks, second row.

Overall, these data show that the shading provided by window treatments impact window luminance. Mesh shades were pulled down at many desks on both floors, even when the sky was overcast. Previous LRC studies showed that occupants tend to minimize the amount of time they change shade positions unless sun is directly hitting their work space. Therefore, it is hypothesized that the occupants simply did not get up to change the mesh shade positions to accommodate for changes in weather conditions. Workers in south-facing spaces take advantage of the two layers of window treatments by moving the blackout shades, but not the mesh shades. Workers adjust blackout shades when they want to limit direct sun; when mesh shades do not fit the window, office supplies provide temporary assistance. One person opened blackout shades when skies were overcast.

Luminaire Monitoring

Mr. Sielcken provided documentation about the lighting controls system (See Appendix D). With this information, installation locations for luminaire monitoring were identified. With assistance from onsite personnel, battery-powered light meters were installed in two locations on the first floor, and one location on the second floor; see Figures 1 and 3 for locations. As shown in Figure 13 below, the devices were oriented so that the sensor measures light passing through uplight slots. Mr. Gasperini's staff retrieved these devices later in January, and returned them to the LRC in a prepaid package.

Figure 13. (A, left) Battery-powered light meters were installed in two locations on the first floor, and one location on the second floor. (B, right) A close-up of the sensor measuring light passing through uplight slots.

LUMINAIRE MONITORING RESULTS

The data indicate that the electric lights operated at full output all day during the cloudy day when most of the measurements were taken (1/7/14). As shown below, the photosensors do, in fact, dim the lights on sunnier days, but only in the north and west control zones. On the south side of the building (where the window shades are commonly down), it appears that the sensors did not see sufficient light to trigger reduced electric light output. This was the case for the January monitoring period; dimming may occur in other months or sky conditions. According to Mr. Sielcken, the lighting controls system was confirmed to be working just a few weeks before this visit.

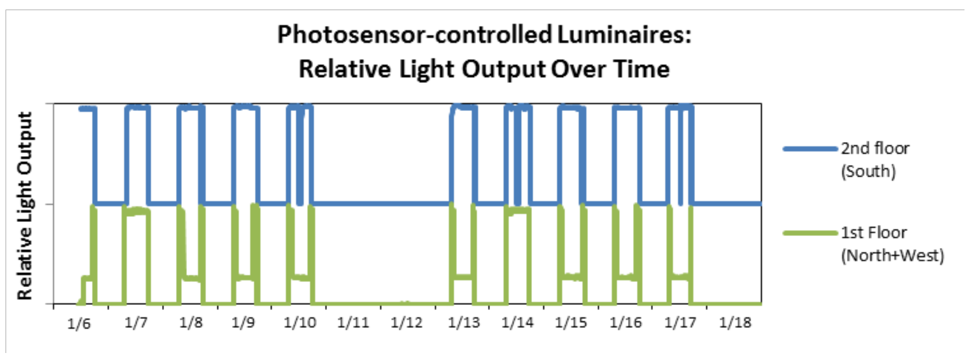


Figure 14. Photosensor-controlled luminaires: relative light output over time.

In the north and west control zones, the rows of lights closest to the windows appear to step down to about 25% of full output on sunny days. The electric light output in these zones did not appear to be continuously variable throughout the day. It should be noted that the photosensors were placed on the ceiling and aimed downwards. They measured the amount of light reflected off desktops.

These data also indicate that the lights are sometimes turned off at lunchtime in the south-facing office (U.S. Army Corps of Engineers). This may have been caused by manual switching, or may have been due to vacancy sensors, but that cannot be determined from site observations.

Desk Monitoring Results (Daysimeter Results)

The graphs below show the averages of the hourly two-week period data collection, expressed in lux and circadian stimulus (CS) values (Figures 15-18).

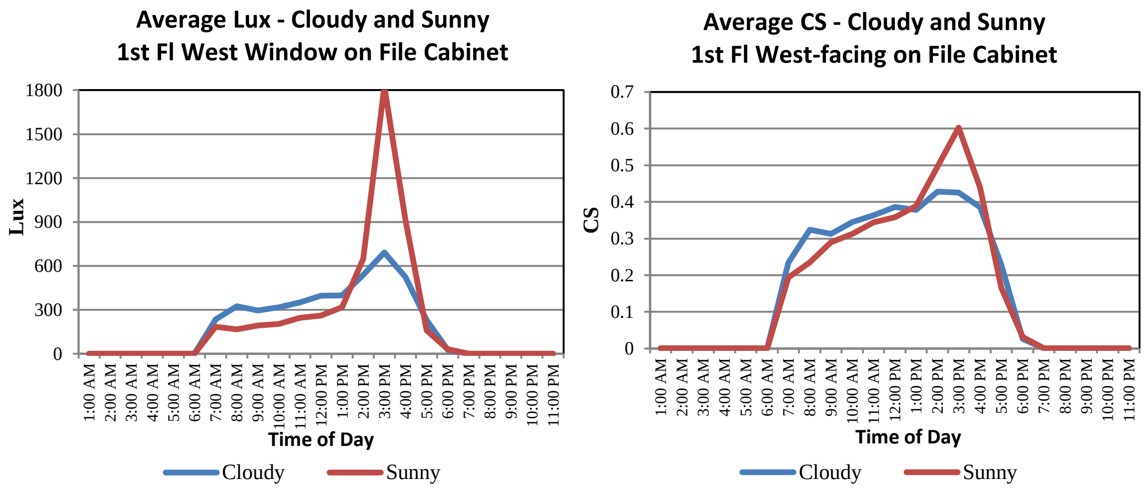


Figure 15. (A, left) Average lux at the first floor west window, from the filing cabinet; (B, right) average CS from the same location.

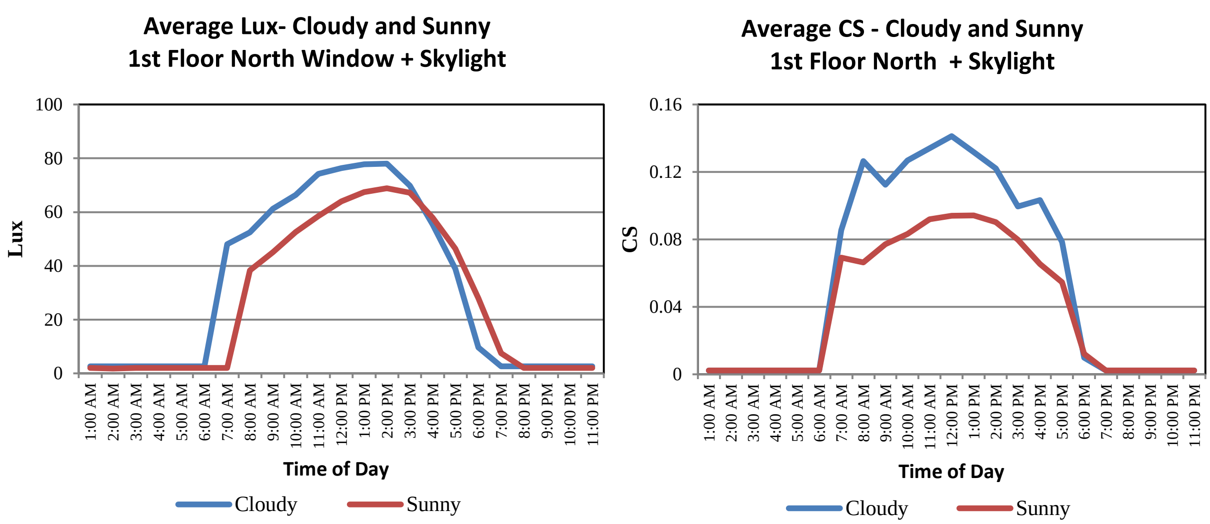
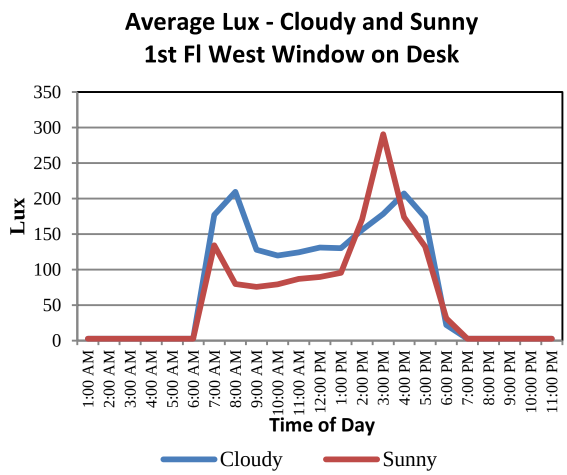


Figure 16. (A, left) Average lux at the first floor north window and skylight; (B, right) average CS from the same location.



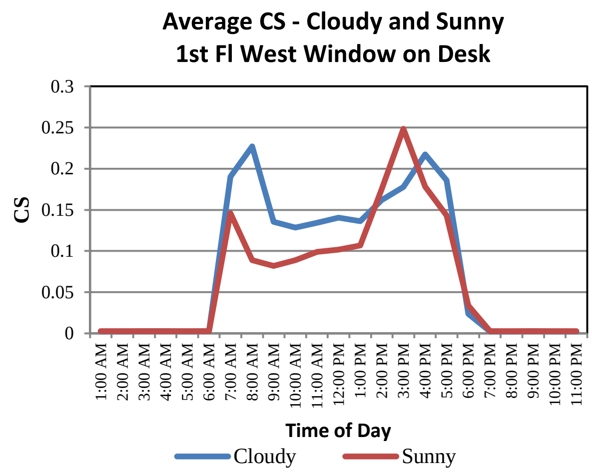
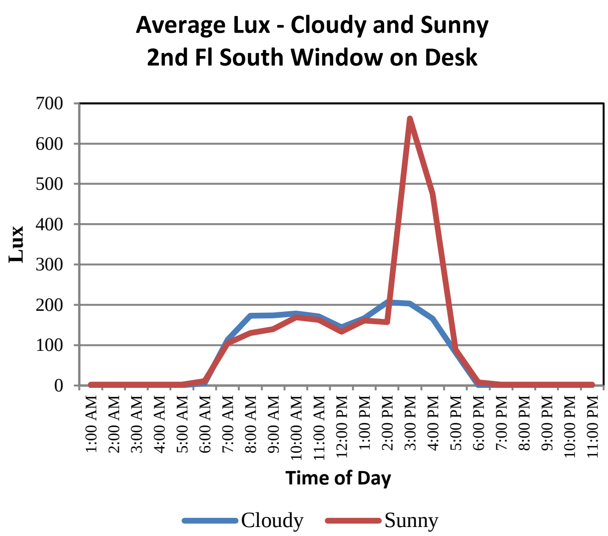


Figure 17. (A, left) Average lux at the first floor west window, from the desk; (B, right) average CS from the same location.



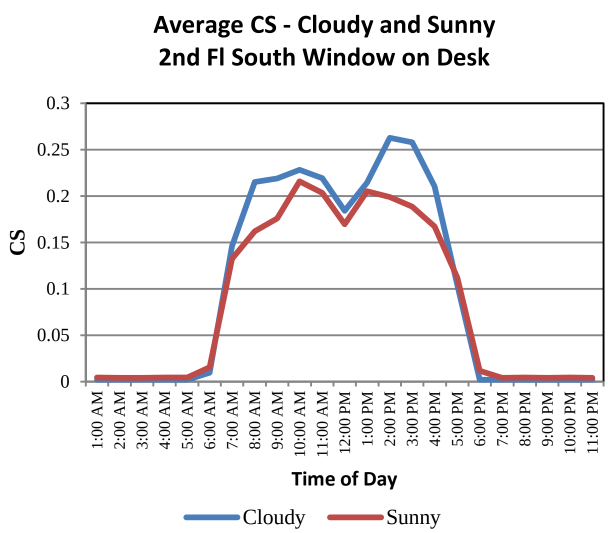


Figure 18. (A, left) Average lux at the second floor south window, from the desk; (B, right) average CS from the same location.

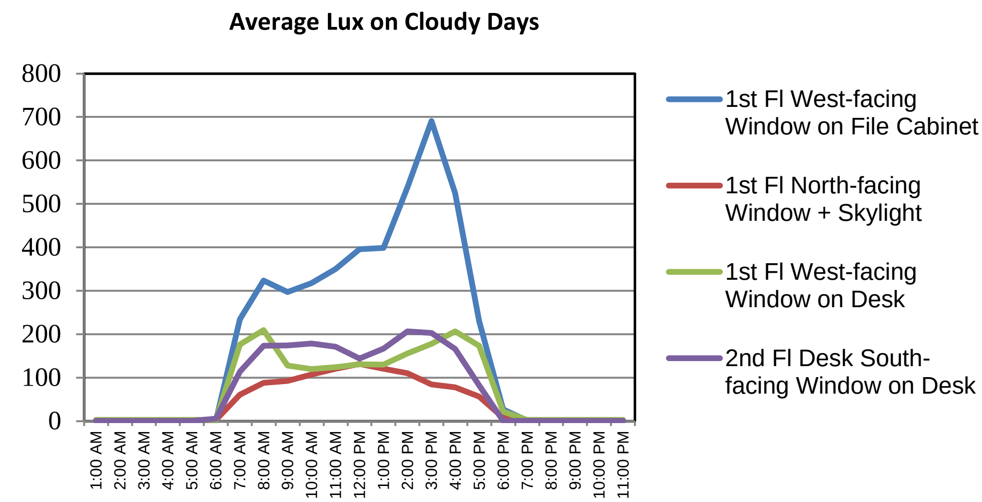


Figure 19. Average lux on cloudy days at all four locations.

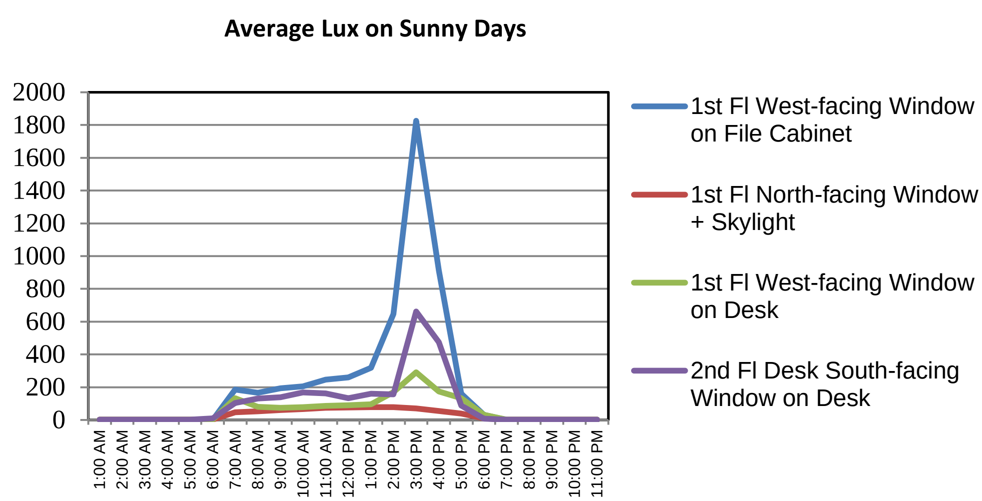


Figure 20. Average lux on sunny days at all four locations.

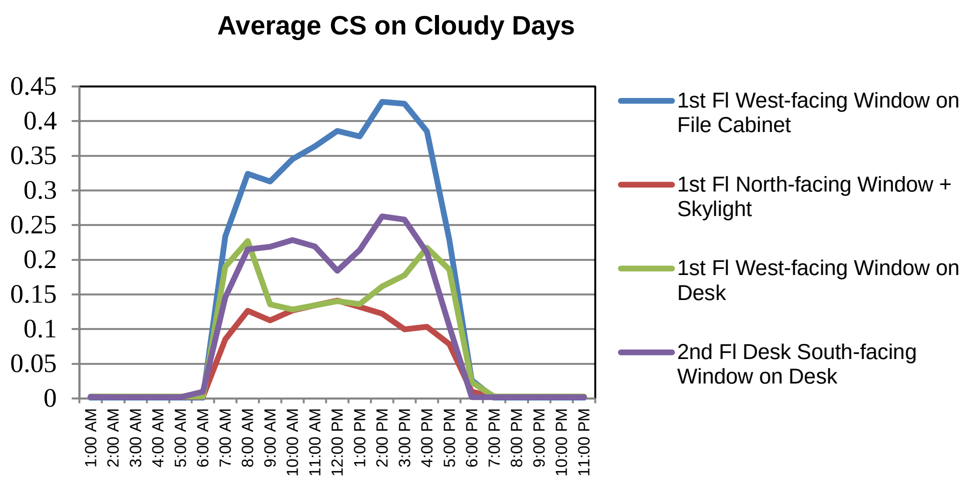


Figure 21. Average CS on cloudy days at all four locations.

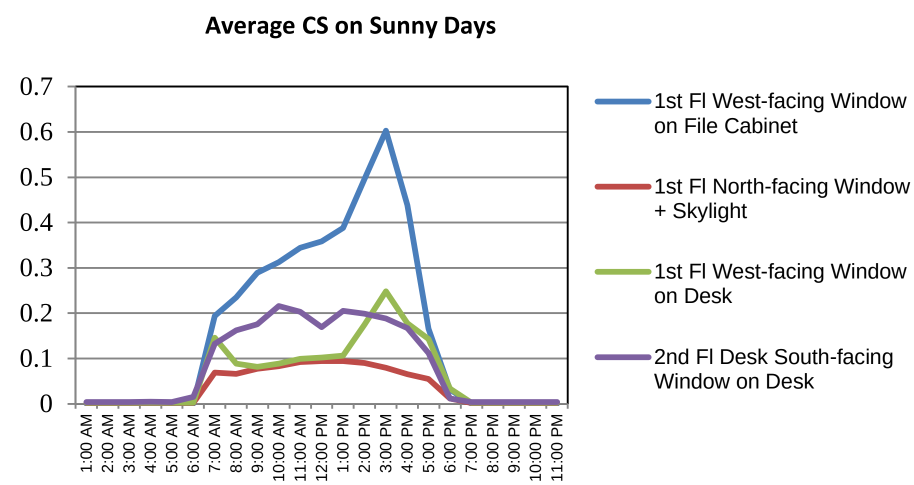


Figure 22. Average CS on sunny days at all four locations.

As shown in Figures 19-22, desks at north- and south-facing windows receive uniform light levels over the course of the day, while west-facing desk spaces tend to have a spike in light levels during the middle to late afternoon. South-facing window desk spaces receive more light during the day, most likely because the blackout shade was retracted, and the desk surface is close to the window, without cubicle wall obstructions. Given that these desk spaces were not occupied, it is not known whether the user of these desk spaces would pull the shades where there is sun (south and west facing), so these spikes/higher light levels would not be observed.

It is interesting to note, however, that except for the device that was placed on top of a file cabinet, all other devices recorded light levels at the eye that are consistent with desk spaces that do not have access to daylight. In other words, the desk spaces located in the second row provide light levels below 200 lux at the eye. In terms of circadian stimulation, again, except for the device placed on top of the cabinet, CS values were below 0.2, which predicts 20% acute melatonin suppression after 1 hour exposure. The daylight contribution does not seem to significantly affect CS values, most likely because the desk spaces we used are farther from the window. While window shade positions may have played a role, it is unlikely that it would have influenced light levels reaching the desk spaces located farther from windows. Figure 23 below shows the relationship of CS and acute melatonin suppression, a marker of activation of the circadian system. Using data from various published studies, the LRC proposed the transfer function between circadian light and acute melatonin suppression shown below. According to this function, the circadian system will not respond to light below 30 lux (either incandescent or daylight) at the cornea, while any light above 1000 lux (i.e., spectrum does not matter in this case) will be at saturation. As shown in the graph in Figure 23, for the same lux levels, daylight is a slightly stronger stimulus for the circadian system than incandescent lamps mainly because it is rich in short-wavelength (blue) light.

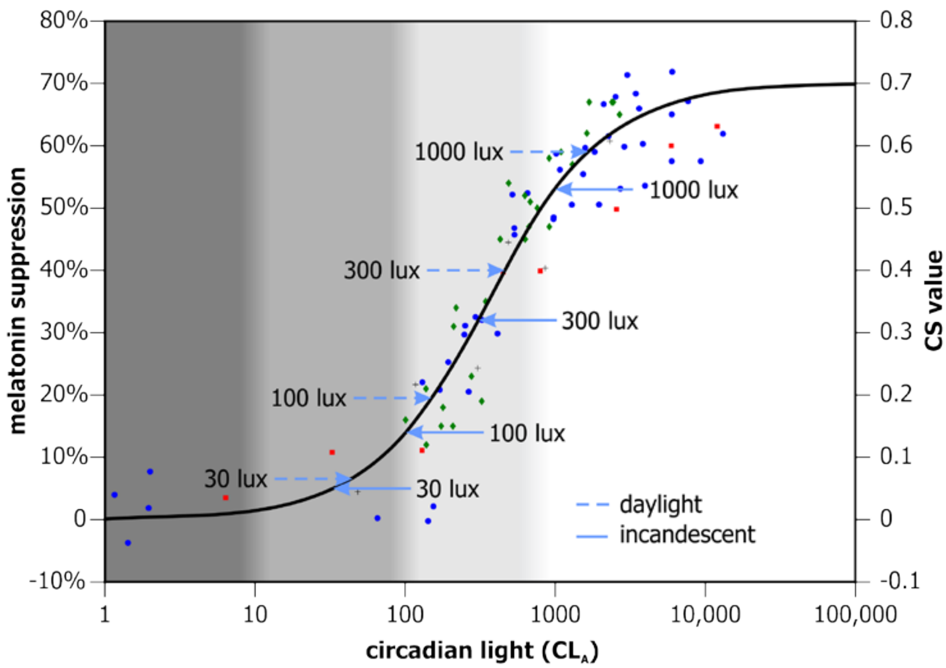


Figure 23. Transfer function between circadian light and acute melatonin suppression, a marker of the circadian system: the relationship between circadian stimulus (CS), circadian light (CL_A), and melatonin suppression measurements.

The report on the results from the Daysimeter data collected from actual users of the buildings will better inform us about the amount of daylight experienced by office workers while sitting at their desk space.

QUESTIONNAIRES

As a result of additional measurements needed on the (sunny) setup day, questionnaire activity was limited at this Grand Junction site. The LRC administered questionnaires to 16 people working in the building. Fifteen of these participants had desks with one or more window orientations (N, S, E, W); one participant had no access to daylight.

Figure 24. A participant completes a questionnaire.

For almost 20 years, the LRC has published a series of lighting case studies that include questionnaire results. This program is called Demonstration and Evaluation of Lighting Technologies and Applications (DELTA). The DELTA publications are available on the LRC website.[5] Where common questions were posed at DELTA office lighting case studies, the LRC compared results to those obtained at the Grand Junction site.

[5] www.lrc.rpi.edu/programs/DELTA/publications/publicationsList.asp

Questionnaire Results

At Grand Junction, most of the respondents (75%) only work in their office during the day.

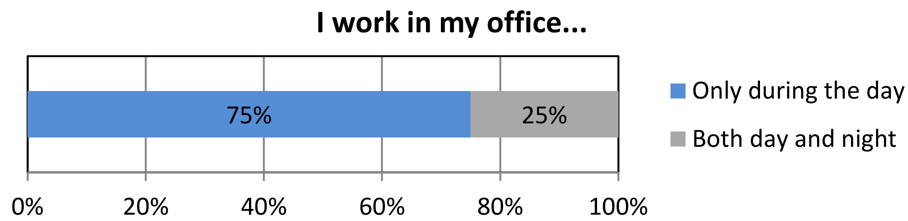


Figure 25. Percentage of Grand Junction workers who work in their office during the day.

The amount of light was rated satisfactory to 63% of Grand Junction respondents; the remaining workers rated the amount of light as "slightly too little." An upcoming DELTA publication will show similar acceptance rates. DELTA publications from the 1990s had slightly different questions; most people did not express extreme opinions about the amount of light.

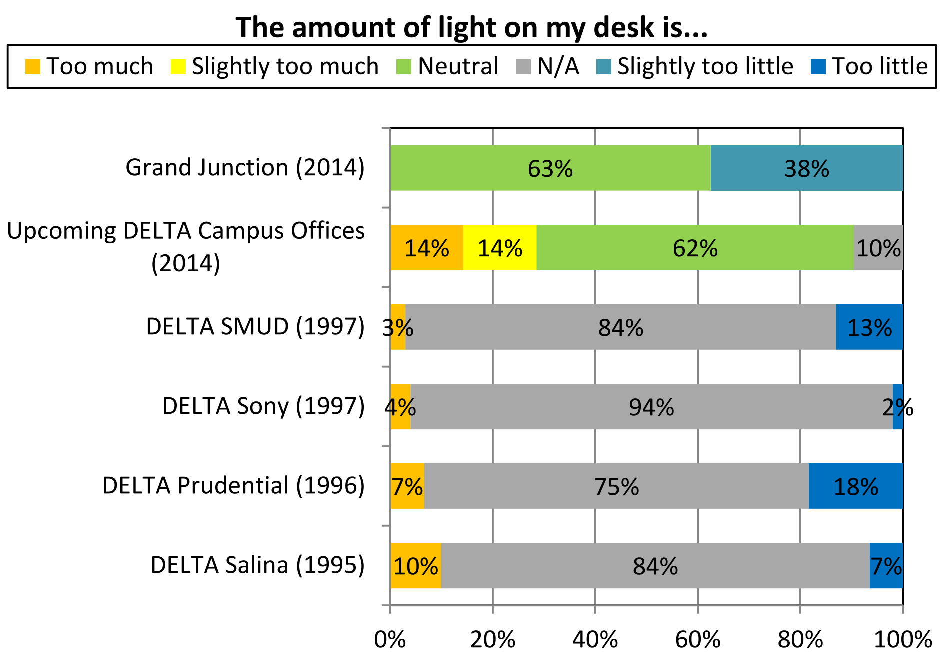


Figure 26. Amount of light on staff desks, comparing responses from Grand Junction to responses from other DELTA reports.

About one-third (31%) of the Grand Junction respondents "always" use a task light, half "never" do, and 19% "sometimes" use a task light. Other DELTA publications do not offer comparison on this task lighting question.

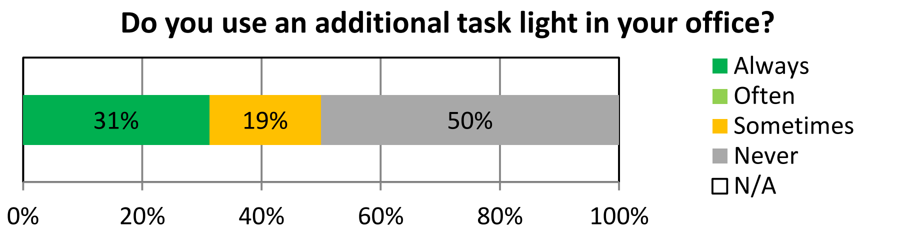


Figure 27. Percentage of Grand Junction respondents who use additional task lights in their offices.

About half of the Grand Junction respondents think the luminaires ("fixtures") and the windows are "comfortable to look at." A significant minority find them "slightly glary" or "very glary." One person did not answer each of these glare questions.

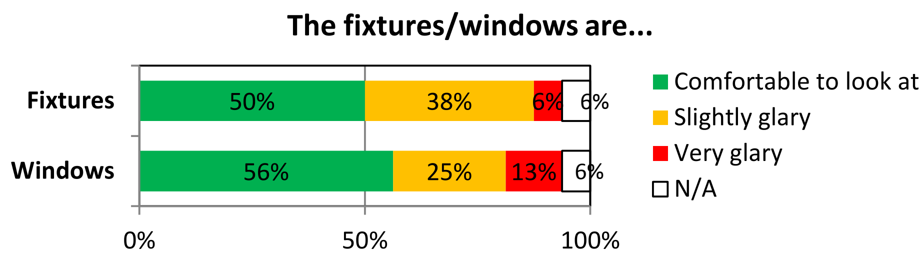


Figure 28. Percentage of respondents who think the fixtures/windows are comfortable or glary.

In other DELTA publications, questionnaires did not address window glare but did address luminaire glare/comfort. Office luminaires are commonly rated as comfortable.

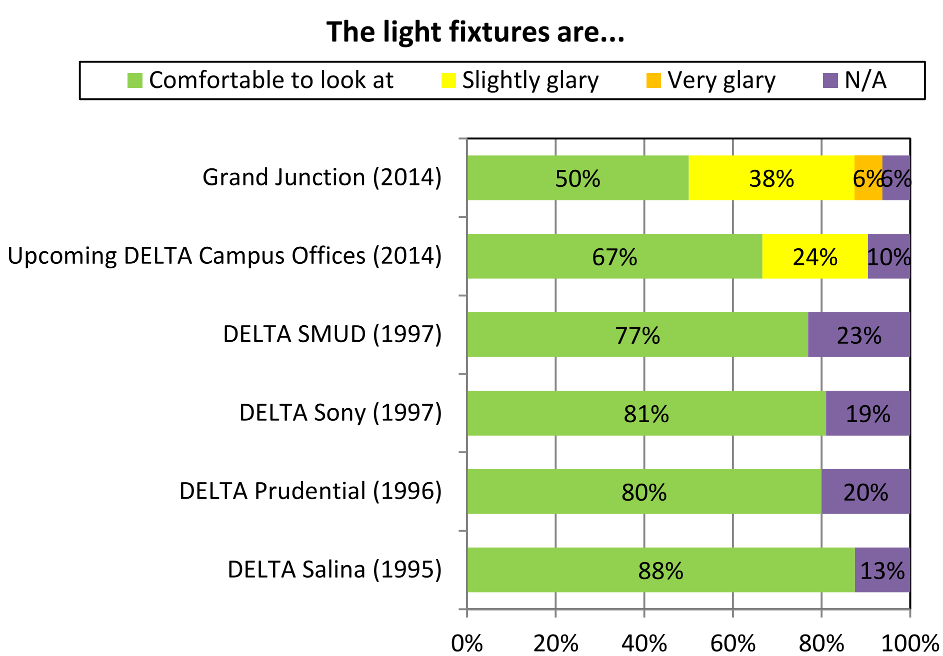


Figure 29. Comparing glare/comfort responses from Grand Junction to responses from other DELTA reports.

In terms of overall lighting quality at Grand Junction, half of the respondents consider this lighting to be "about the same" as other offices. About one-third think the lighting is "better" or "much better," and 13% think the lighting is "worse."

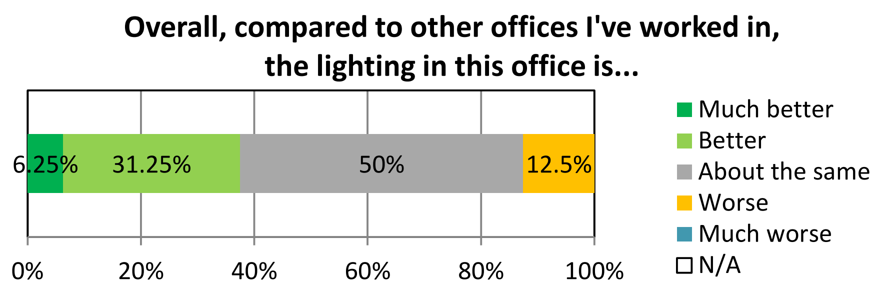


Figure 30. Grand Junction staff responses regarding the lighting in their office, compared to other offices.

Grand Junction occupants have similar overall feedback to most other DELTA office lighting case studies.

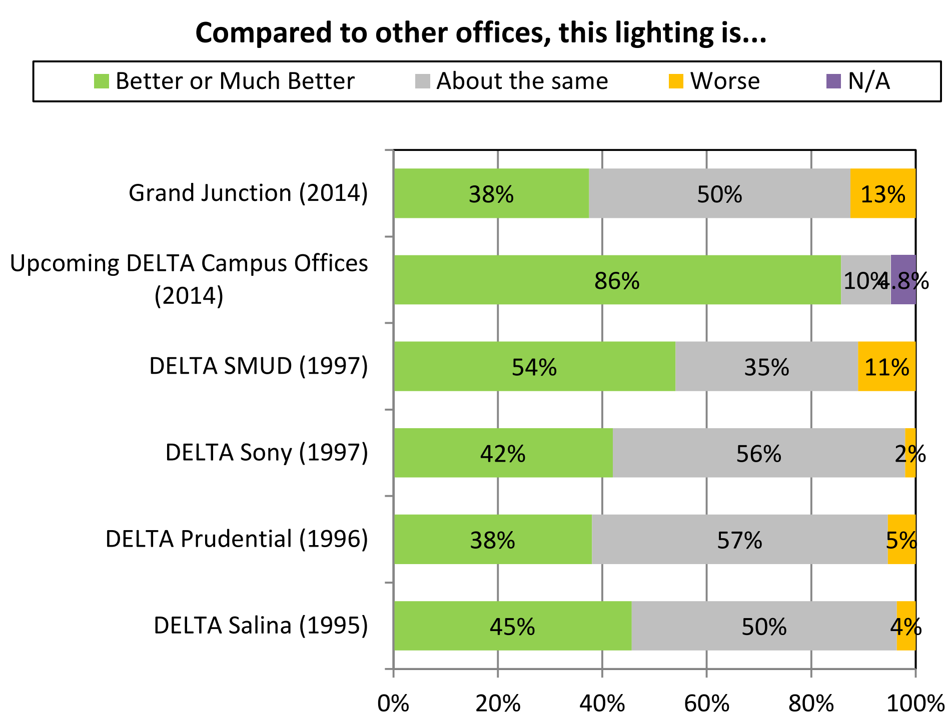


Figure 31. Comparing responses from Grand Junction to responses from other DELTA reports, regarding the lighting.

At Grand Junction, there were a few complaints about the photosensor lighting controls:

- "Lights are automatic and sometimes dim without cause."
- "It's good lighting as long as the lights stay on… Sometimes in the morning they are on, then [when the] sun comes up, they dim too much. So, we have to walk to [the receptionist's] desk to override [the controls]."

- "My [private] office tends to be too dark. The automatic sensors usually darken my room especially right after I turn on the lights. They slowly darken to off and I am too lazy to keep getting up and turning the lights on."

There was one complaint about a false-off due to a vacancy sensor in a largely-vacant, open-plan office:

- "I'm the only one who works on this side, so sometimes the lights go off." Subject reports that she has to get up and move to keep the lights on.

Regarding task lights:

- Subject needs a task light: "I bought one but I'm just too impatient to set it up."
- The LRC noted that one person brought in an additional task light, operating a 60W neodymium incandescent lamp. This is used in addition to linear fluorescent under-cabinet lighting. One 4-ft. segment of the overhead luminaire is non-operational.

On lighting in general:

- Subject has a private office and does not turn on overhead lights. "I just don't like [fluorescent lighting], it just doesn't work for me." But subject rated overall lighting as "better" because her previous office didn't have a window.

DISCUSSION

In general, the overall impression from the responses of workers in the Aspinall Federal Building was that the light levels were slightly too low and some of them felt the need to add task lighting to compensate for that. It was interesting to note that workers felt that the luminaires were slightly glary. This might have to do with the fact that the space looked dim and therefore, the luminaires would appear brighter in that context.

Researchers observed that occupants did not open the mesh shades once they were adjusted to reduce glare or direct sun. This may have an impact on lighting energy savings because it minimizes the amount of daylight available to trigger the photosensors. The use of shades on a continuous basis vs. a temporary basis may also affect circadian health if shades reduce light to levels that are not effective in suppressing melatonin. If lighting controls are adjusted to dim lights less aggressively such that higher illuminances are maintained on the work plane, comfort ratings may be improved. This action, however, may increase energy use.

A DELTA publication featured offices at Sacramento Municipal Utilities District (SMUD) where daylighting and photosensor lighting controls worked successfully. The SMUD building used light shelves on south facing windows, skylights on the top floor, and vertical window blinds. The photosensors are installed in the pendant luminaires, and are programmed to maintain at least 30 fc on the work plane. None of the daytime measurements at SMUD were lower than the nighttime measurements. While the questionnaire at SMUD did not address window glare, overall ratings appear to be higher than at the Grand Junction site.

MAINTENANCE INTERVIEW

The LRC researcher interviewed Mr. Gasperini, the property manager, about maintenance of the electric lighting.

Mr. Gasperini indicated that the installation was performed in stages with floors 2-3 occupied in May 2012, and the first floor occupied in June 2013. Any warranty issues that have occurred are addressed by Mr. Sielcken. Mr. Gasperini reported that in the first 6 months of occupancy, there were widespread problems with fluorescent ballast failures. The manufacturer has reportedly provided replacements and has extended their warranty. The building stores 20 replacement ballasts at all times. The LRC researcher did notice a few luminaires on the first floor with low or no output, possibly due to ballast failure.

There were no reports of widespread premature lamp failures. Mr. Gasperini produced samples of the T8 linear fluorescent lamps in use in the building: 3500K, 70-80^{+} CRI, as shown in Figure 32.

Figure 32. Sample fluorescent lamps.

DAYSIMETER RESULTS

The static Daysimeter results, while not representative of what the office workers are actually experiencing, provide us with some continuous measurements of the lighting in a few spaces in the building, given that the other photometric measurements were simply a snapshot in time. From the Daysimeter measurements, it seems that desk spaces that are located in the second row (far from windows) are receiving very little contribution of daylight. It is also not clear how these light level measurements would change with occupancy.

LESSONS LEARNED

- On the north and west exposures, illuminance measurements at the second row of desks were consistently lower than the first row of desks. Most of these desks were vacant however, and the lower light levels may explain the reason why these desks are not preferred by users. This might be something to keep in mind if staffing expands to full occupancy at some point.
- One row of desks (on north side) had no overhead lighting, and therefore, had the lowest light levels (4-19 fc without the task light on). These desks sit vacant, so no complaints about these specific desk spaces were registered in the questionnaires. Again, low light levels may explain why these desks are not in use and may generate complaints if occupied in the future.
- On the north and west sides of the first floor, the photosensor dimming system appears to aggressively step down light output to about 25% of full light output on sunny days. Output does not appear to be continuously variable throughout the day, but instead appears to step down abruptly and stay low throughout the day until late afternoon when it steps up again abruptly. The LRC researcher observed this step-up in light output in the first afternoon of the visit.
    - Three of 16 questionnaire participants had negative comments about the photosensor operation.
    - The controls system may need to be adjusted so that light levels are not allowed to drop lower on sunny days than on cloudy days or after dark. However this would translate to less lighting energy savings.
- During this winter monitoring period, the lights in the south-facing control zone (second floor) do not appear to be dimming in response to sunny weather; these spaces use shades extensively, so the photosensor mounted indoors may not be "seeing" enough light to trigger dimming of the lights; arguably, this is a good strategy to prevent desk spaces from becoming too dim. However, this means that the investment in photosensors and dimming equipment for south-facing offices is not being put to use in the winter.
- Occupants commonly orient their seating positions to face away from windows. Window luminances vary over time, so occupants use shades if available. However, occupants do not commonly retract shades when cloudy, which may cause photosensors to keep electric lights at full output. Since the photosensors are indoors and are affected by shading, some energy savings could be achieved on cloudy days if staff were encouraged to re-open their window shades.
    - One person devised an additional shading device for low winter sun.
- Most Grand Junction questionnaire respondents have enough light for work; some (38%) think there is slightly too little light. The photosensors appear to dim the lights too much when sunny.
- About half of the respondents think the luminaires and the windows are comfortable to look at; the remaining responses were "slightly glary" or "very glary."
- There were widespread problems with fluorescent ballasts within the first year of occupancy, but after warranty replacement, ballasts are now functioning as expected. Lamp failures have not been problematic at this site.

- Light levels from the Daysimeters showed that in offices in the second row (far from windows), the amount of circadian stimulation is low, typically below 0.2 lux. The only measurement that showed a significant amount of circadian stimulus was when the device was placed on top of the file cabinet, suggesting that even though partitions provide the worker with some privacy, they also reduce access to daylight coming from windows. It will be interesting to compare the measurements obtained with the static Daysimeters to those obtained with devices worn by workers.

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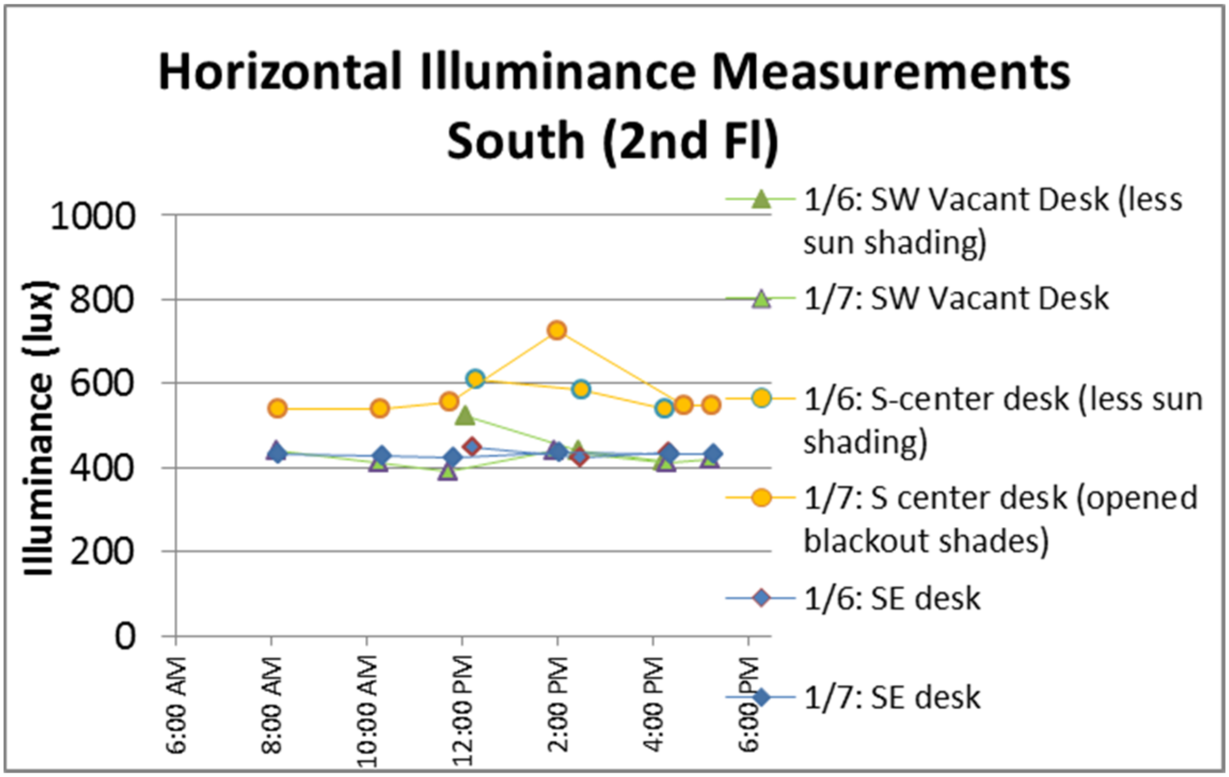
APPENDIX A: PHOTOMETRIC MEASUREMENTS FOR SOUTH EXPOSURE

					Task Light On		Task Light Off			
	Floor	Orientation	Row	Desk	Horiz Desk (lux)	Vert Surface (lux)	Horiz Desk (lux)	Vert Surface (lux)	Notes	Luminance (cd/m2)
1/6/14 12:05 PM	2	South	1	SW Vacant desk	N/A		521	220	Mesh shades only	360
1/6/14 2:25 PM	2	South	1				440	226	Mesh shades only	320
1/6/14 4:12 PM	2	South	1				417	229	Mesh shades only	146
1/7/14 8:06 AM	2	South	1				442	205	Mesh shades only	N/A dark outside
1/7/14 10:15 AM	2	South	1				411	226	Mesh shades only	74
1/7/14 11:43 AM	2	South	1				391	226	Mesh shades only	110
1/7/14 1:56 PM	2	South	1				442	236	Mesh shades only	406
1/7/14 4:17 PM	2	South	1				411	214	Mesh shades only	85
1/7/14 5:12 PM	2	South	1				421	222	Mesh shades only	11
1/6/14 12:17 PM	2	South	1	S Center	N/A		608	356	Blackout + mesh shades	373
1/6/14 2:30 PM	2	South	1				583	342	Blackout + mesh shades	198
1/6/14 4:15 PM	2	South	1				541	310	Blackout + mesh shades	90
1/7/14 8:08 AM	2	South	1				538	293	Blackout + mesh shades	N/A dark outside
1/7/14 10:18 AM	2	South	1				540	295	Blackout + mesh shades	95
1/7/14 11:45 AM	2	South	1				557	320	Blackout shades OPEN now	1450
1/7/14 2:00 PM	2	South	1				725	469	Only mesh shades, cont.	4500
1/7/14 4:40 PM	2	South	1				549	310	Only mesh shades, cont.	1270
1/7/14 5:15 PM	2	South	1				549	286	Only mesh shades, cont.	64
1/6/14 12:12 PM	2	South	1	SE	N/A		447	246	Blackout + mesh shades	234
1/6/14 2:28 PM	2	South	1				423	235	Blackout + mesh shades	153
1/6/14 4:20 PM	2	South	1				436	228	Blackout + mesh shades	75
1/7/14 8:09 AM	2	South	1				431	200	Blackout + mesh shades	N/A dark outside
1/7/14 10:20 AM	2	South	1				427	212	Blackout + mesh shades	110
1/7/14 11:48 AM	2	South	1				425	216	Blackout + mesh shades	118
1/7/14 2:02 PM	2	South	1				438	224	Blackout + mesh shades	406
1/7/14 4:22 AM	2	South	1				433	223	Blackout + mesh shades	69
1/7/14 5:16 PM	2	South	1				433	222	Blackout + mesh shades	7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South (2nd Fl)
Illuminance (lux)
1000
800
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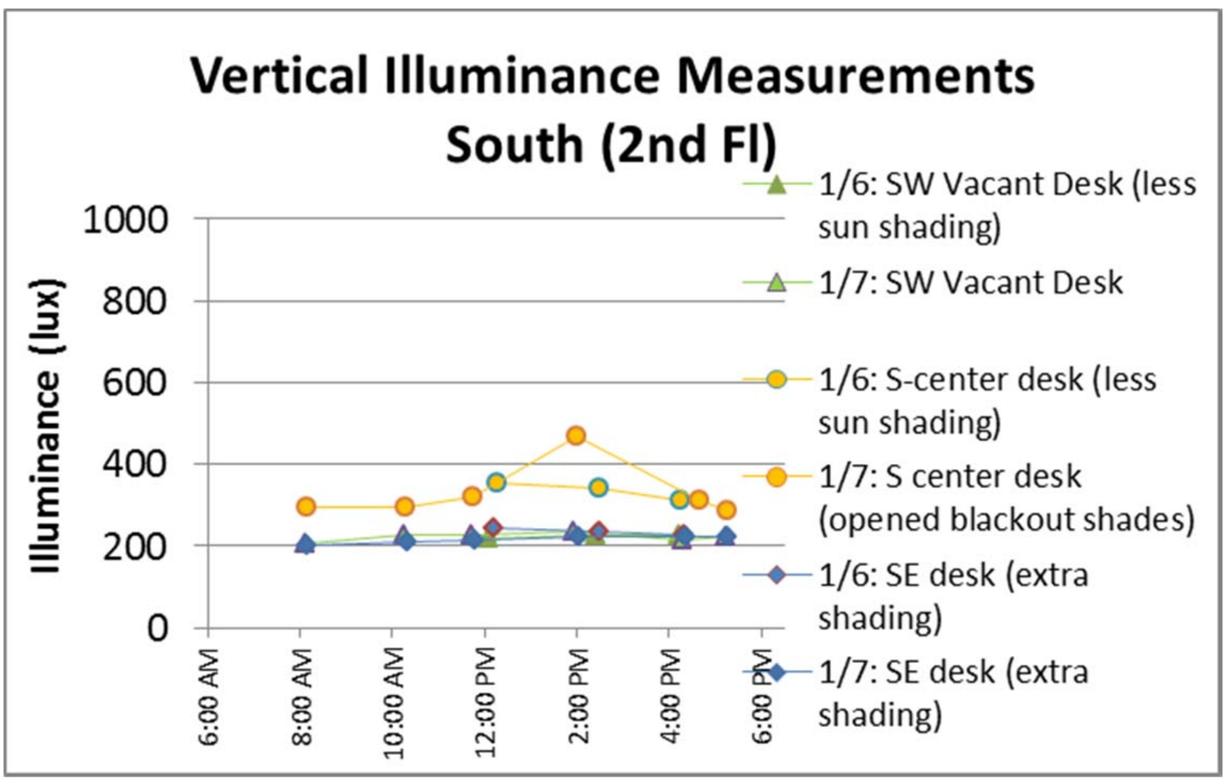
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: SW Vacant Desk (less sun shading)
1/7: SW Vacant Desk
1/6: S-center desk (less sun shading)
1/7: S center desk (opened blackout shades)
1/6: SE desk
1/7: SE desk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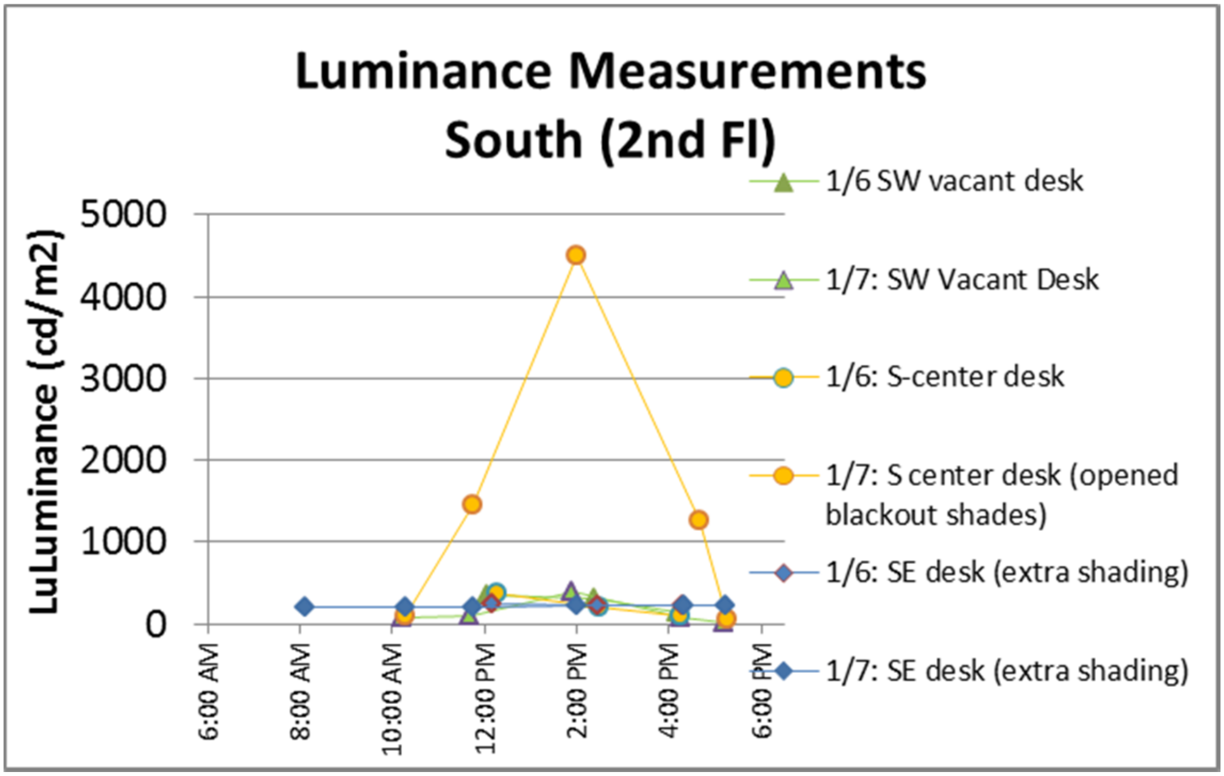
1/6: SW Vacant Desk (less sun shading)
1/7: SW Vacant Desk
1/6: S-center desk (less sun shading)
1/7: S center desk (opened blackout shades)
1/6: SE desk (extra shading)
1/7: SE desk (extra shading)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8:00 AM
10:00 AM
12:00 PM
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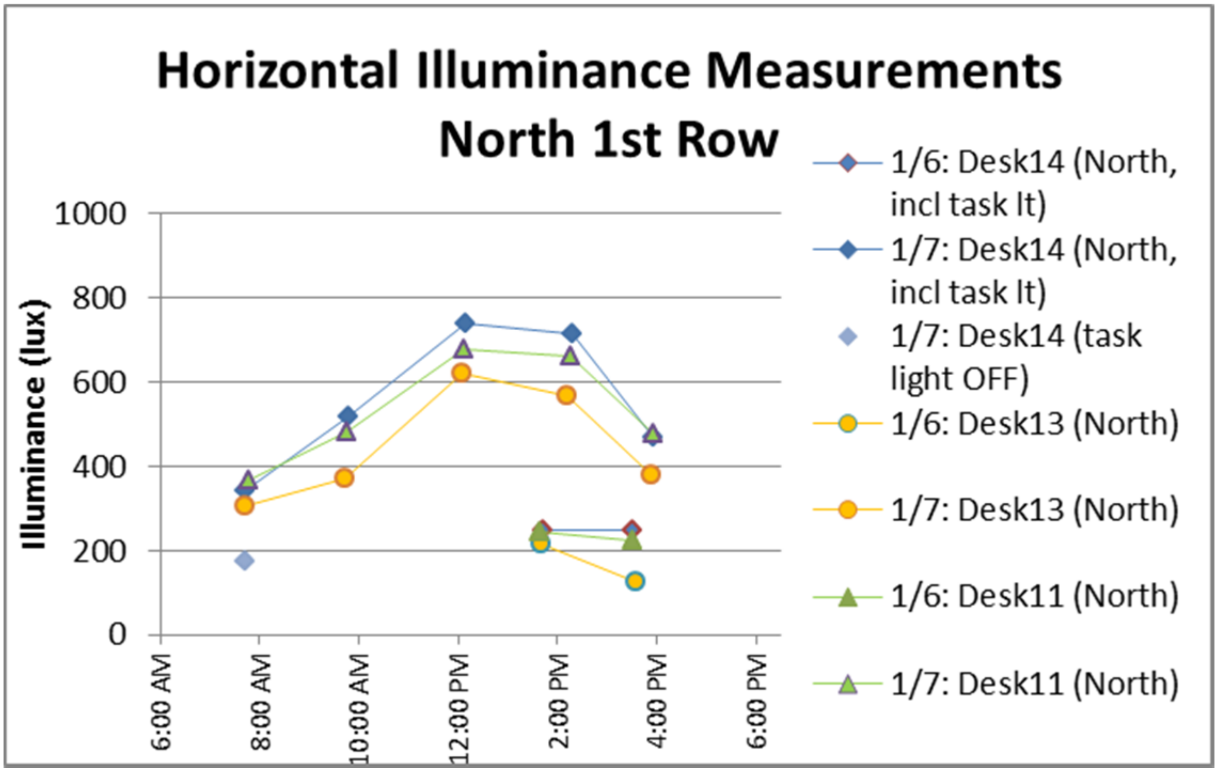
4:00 PM
6:00 PM
1/6 SW vacant desk
1/7: SW Vacant Desk
1/6: S-center desk
1/7: S center desk (opened blackout shades)
1/6: SE desk (extra shading)
1/7: SE desk (extra shading)

APPENDIX B: PHOTOMETRIC MEASUREMENTS FOR NORTH EXPOSURE

					Task Light On		Task Light Off			
	Floor	Orientation	Row	Desk	Horiz Desk (lux)	Vert Surface (lux)	Horiz Desk (lux)	Vert Surface (lux)	Notes	Luminance (cd/m2)
1/6/14 1:43 PM	1	North	1	#14	249	421			Undercabs and desk lamp on, no shades	3001
1/6/14 3:31 PM	1	North	1		250	325			Same status	2005
1/7/14 7:42 AM	1	North	1		341	248	177	91	Measured w/ and w/o task light	N/A dark outside
1/7/14 9:48 AM	1	North	1		518	569			Same status	3000
1/7/14 12:09 PM	1	North	1		739	770			Same status	2900
1/7/14 2:18 PM	1	North	1		717	858			Same status	3620
1/7/14 3:56 PM	1	North	1		470	458			Same status	973
1/6/14 1:41 PM	1	North	1	#13			215	349	task lights off, no shades	3246
1/6/14 3:34 PM	1	North	1				125	222	task lights off, no shades	2110
1/7/14 7:43 AM	1	North	1				304	40	task lights off, no shades	N/A dark outside
1/7/14 9:44 AM	1	North	1				371	147	hazy clouds, some blue sky	2987
1/7/14 12:05 PM	1	North	1				619	230	all overcast	2840
1/7/14 2:12 PM	1	North	1				568	426	"I've never turned them on (task light). I hate light!"	3000
1/7/14 3:53 PM	1	North	1				379	155	task lights off, no shades	1030
1/6/14 1:38 PM	1	North	1	#11			245	315	No task lights, no shades	3716
1/6/14 3:30 PM	1	North	1				224	251	No task lights, no shades	2827
1/7/14 7:46 AM	1	North	1				366	53	No task lights, no shades	N/A dark outside
1/7/14 9:46 AM	1	North	1				480	291	No task lights, no shades	2400
1/7/14 12:07 PM	1	North	1				680	523	No task lights, no shades	1900
1/7/14 2:16 PM	1	North	1				661	502	No task lights, no shades	2520
1/7/14 3:55 PM	1	North	1				477	215	No task lights, no shades	820
1/6/14 1:46 PM	1	North	2	#15			120	59	No task lights, shades N/A	1084
1/6/14 3:37 PM	1	North	2				105	62	No task lights, shades N/A	783
1/7/14 7:56 AM	1	North	2				64	93	No task lights, shades N/A	N/A dark outside
1/7/14 9:51 AM	1	North	2				110	106	No task lights, shades N/A	1040
1/7/14 12:11 PM	1	North	2				185	140	No task lights, shades N/A	1300
1/7/14 2:21 PM	1	North	2				191	131	No task lights, shades N/A	1120
1/7/14 3:58 PM	1	North	2				99.5	104	No task lights, shades N/A	490
1/6/14 1:52 PM	1	North	2	#16			128	88	No task lights, shades N/A	835
1/6/14 3:39 PM	1	North	2				111	68	No task lights, shades N/A	610
1/7/14 7:57 AM	1	North	2				45	30	No task lights, shades N/A	N/A dark outside
1/7/14 9:54 AM	1	North	2				120	87	No task lights, shades N/A	1870
1/7/14 12:13 PM	1	North	2				200	164	No task lights, shades N/A	1980
1/7/14 2:22 PM	1	North	2				222	164	No task lights, shades N/A	2600
1/7/14 3:59 PM	1	North	2				93	64	No task lights, shades N/A	958
1/6/14 1:56 PM	1	North	2	#17			103	76	No task lights, shades N/A	1041
1/6/14 3:41 PM	1	North	2				105	63	No task lights, shades N/A	1004
1/7/14 7:59 AM	1	North	2				41	67	No task lights, shades N/A	N/A dark outside
1/7/14 9:56 AM	1	North	2				118	108	No task lights, shades N/A	1041
1/7/14 12:15 PM	1	North	2				204	172	No task lights, shades N/A	2540
1/7/14 2:25 PM	1	North	2				202	162	No task lights, shades N/A	2870
1/7/14 4:00 PM	1	North	2				85	88	No task lights, shades N/A	570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North 1st Row
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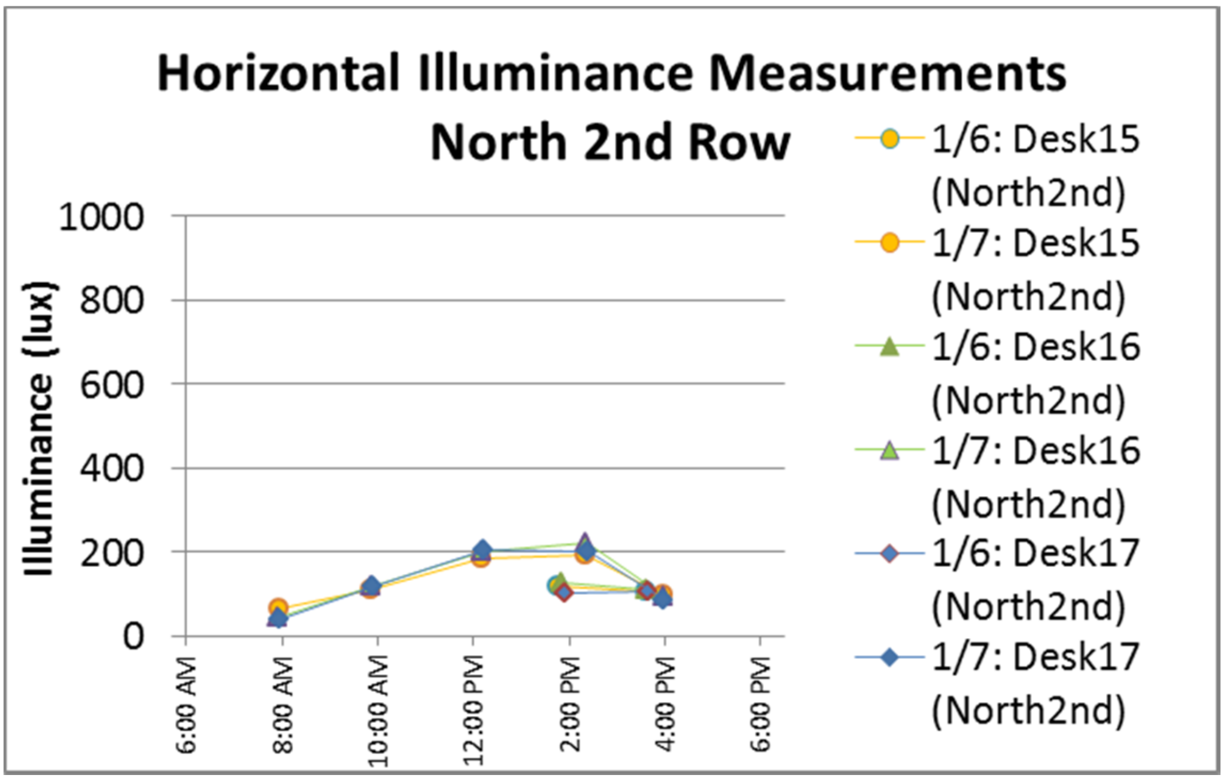
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk14 (North, incl task lt)
1/7: Desk14 (North, incl task lt)
1/7: Desk14 (task light OFF)
1/6: Desk13 (North)
1/7: Desk13 (North)
1/6: Desk11 (North)
1/7: Desk11 (North)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North 2nd Row
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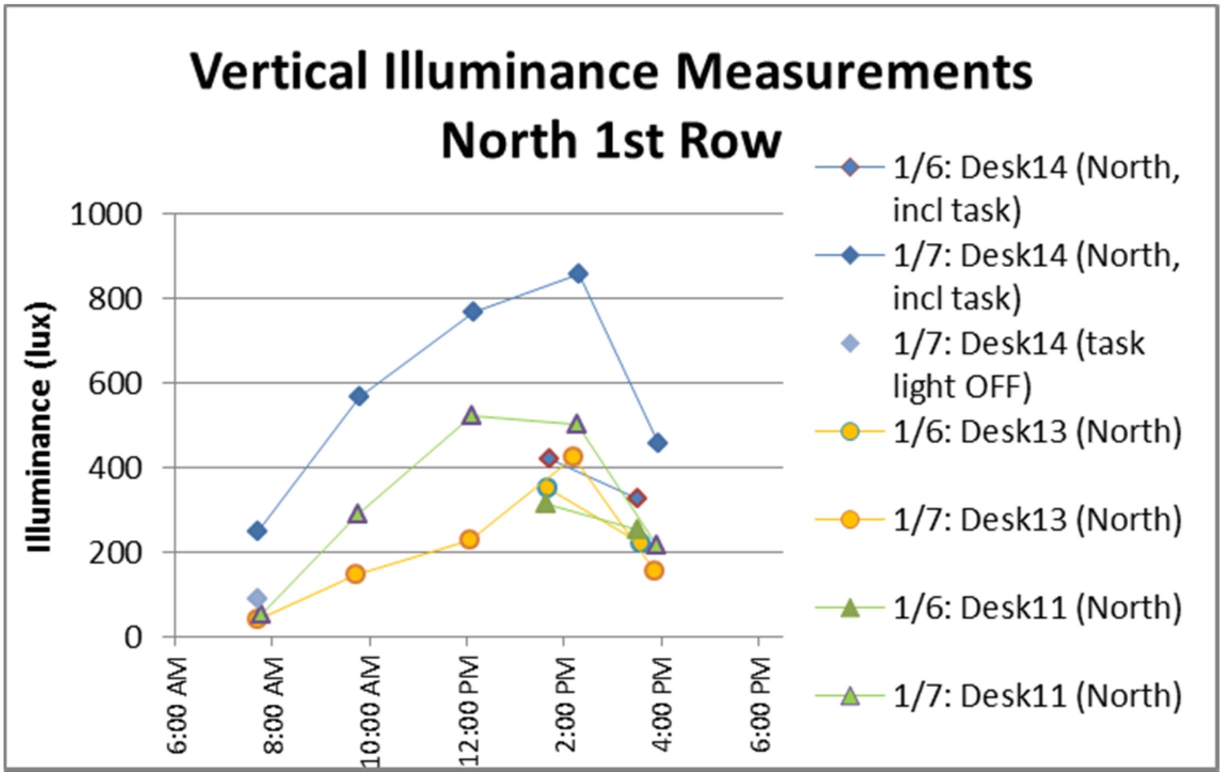
2:00 PM
4:00 PM
6:00 PM
1/6: Desk15 (North2nd)
1/7: Desk15 (North2nd)
1/6: Desk16 (North2nd)
1/7: Desk16 (North2nd)
1/6: Desk17 (North2nd)
1/7: Desk17 (North2nd)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Illuminance (lux)
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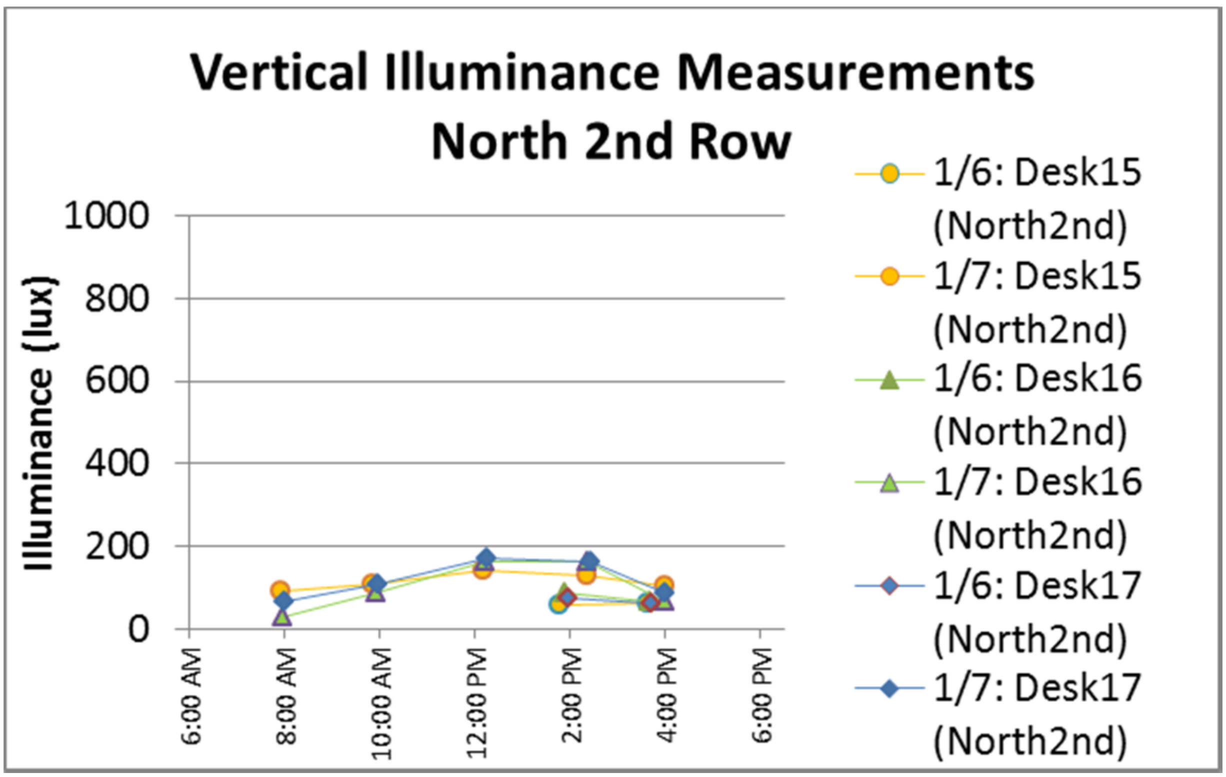
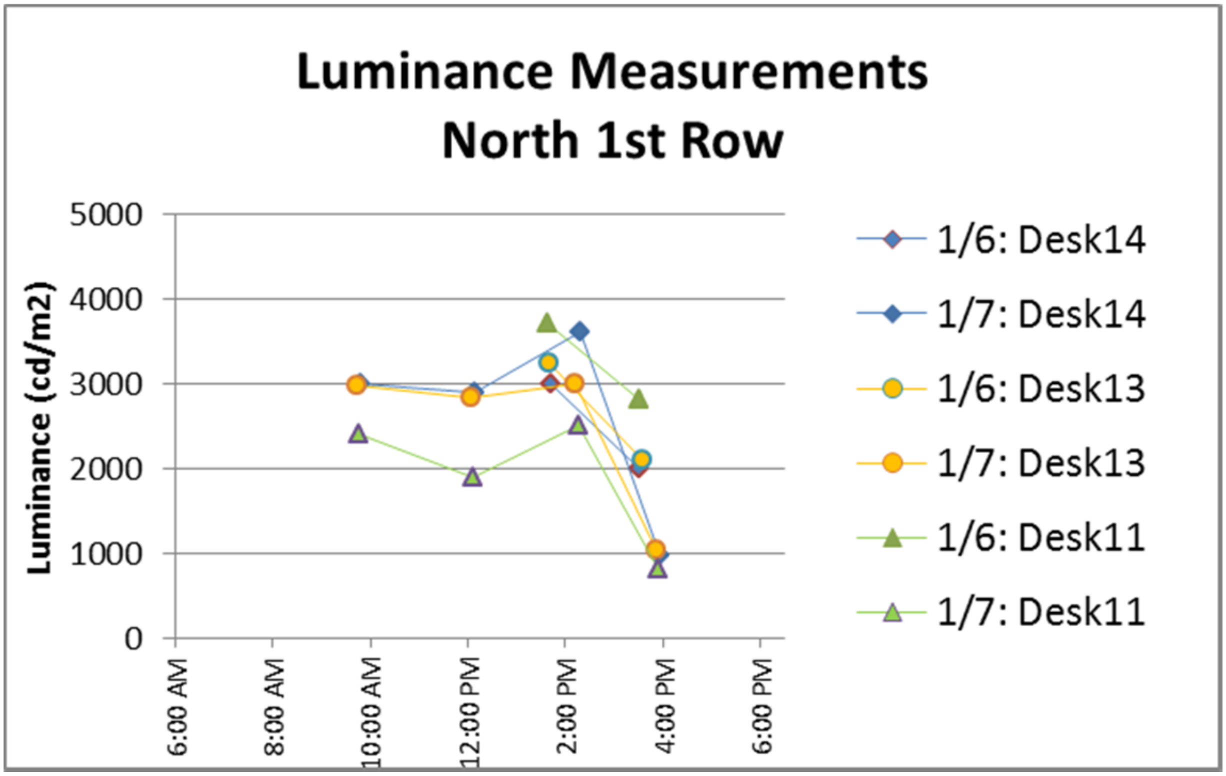
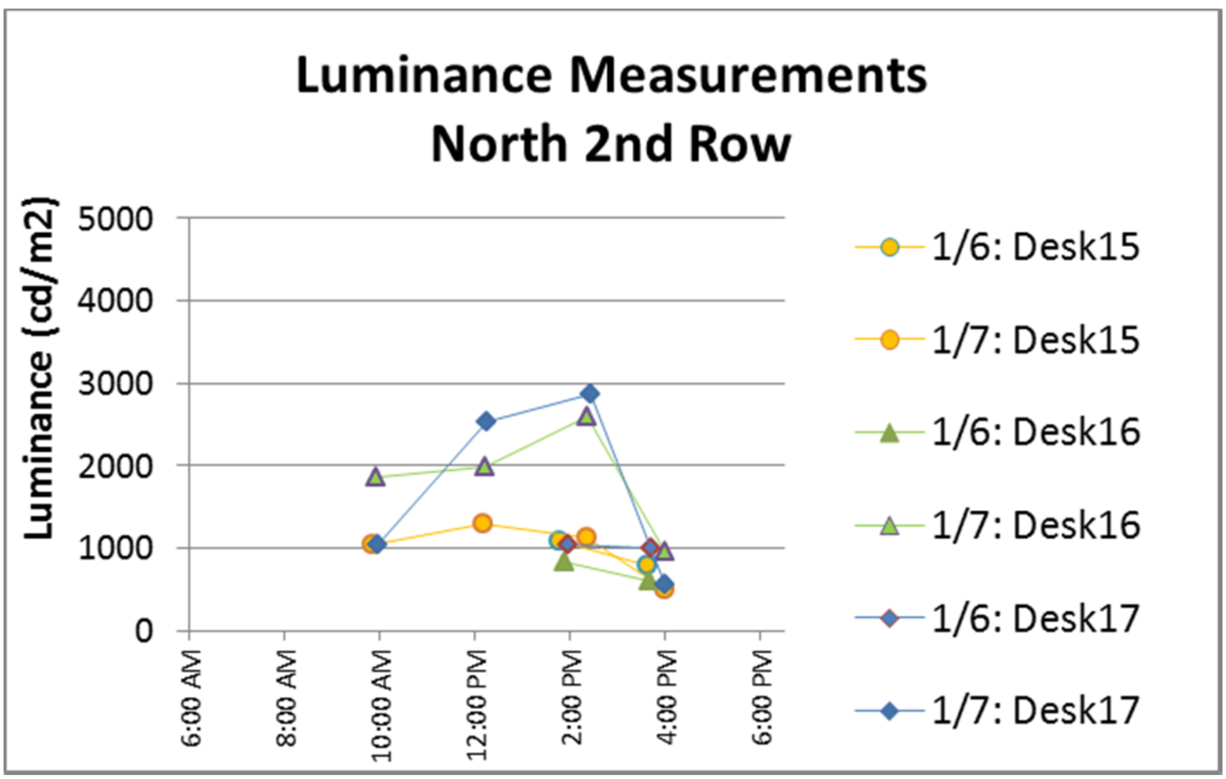
4:00 PM
6:00 PM
1/6: Desk14 (North, incl task)
1/7: Desk14 (North, incl task)
1/7: Desk14 (task light OFF)
1/6: Desk13 (North)
1/7: Desk13 (North)
1/6: Desk11 (North)
1/7: Desk11 (North)

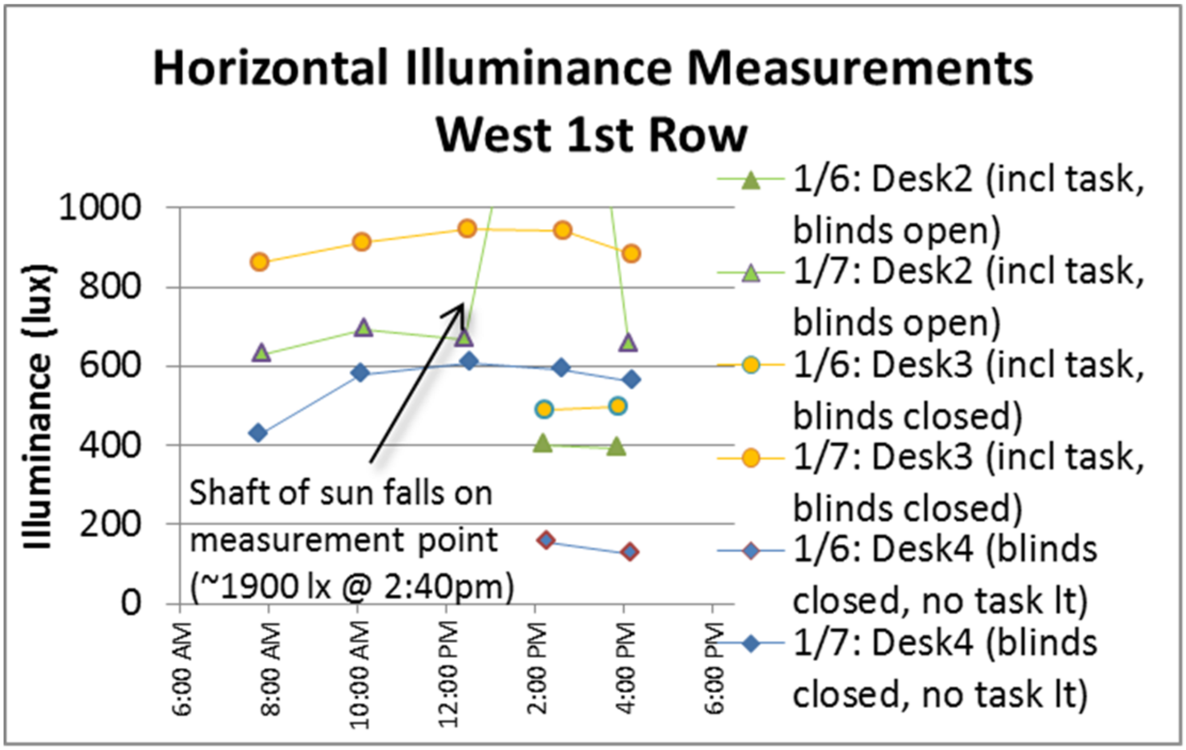

Vertical Illuminance Measurements
North 2nd Row
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk15 (North2nd)
1/7: Desk15 (North2nd)
1/6: Desk16 (North2nd)
1/7: Desk16 (North2nd)
1/6: Desk17 (North2nd)
1/7: Desk17 (North2nd)

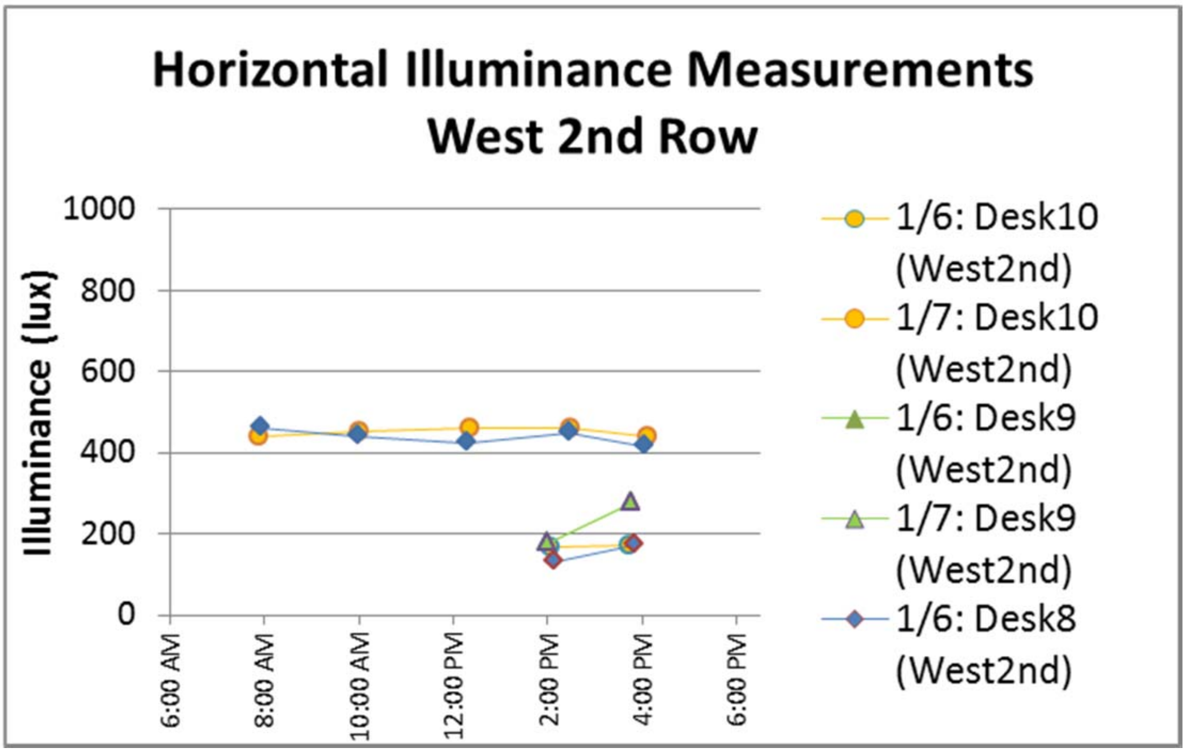

Luminance Measurements
North 1st Row
Luminance (cd/m2)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk14
1/7: Desk14
1/6: Desk13
1/7: Desk13
1/6: Desk11
1/7: Desk11

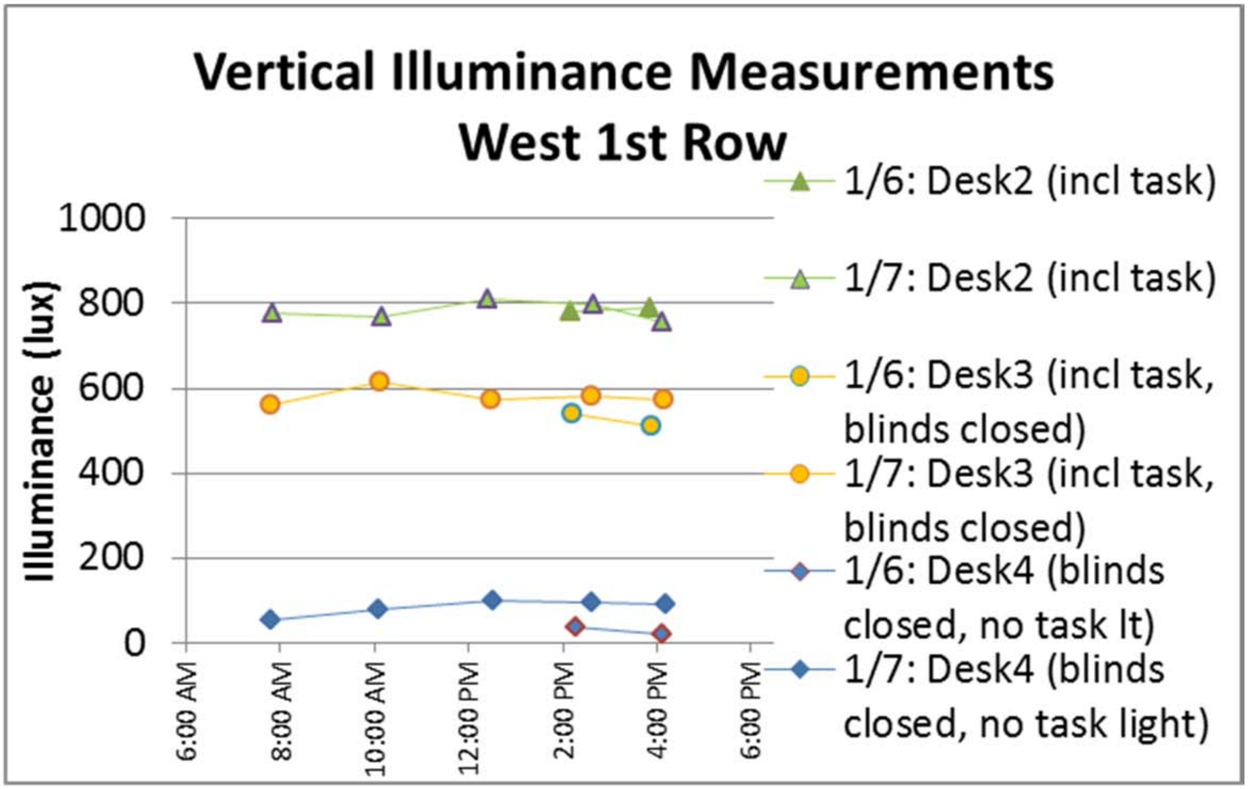

Luminance Measurements
North 2nd Row
Luminance (cd/m2)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk15
1/7: Desk15
1/6: Desk16
1/7: Desk16
1/6: Desk17
1/7: Desk17

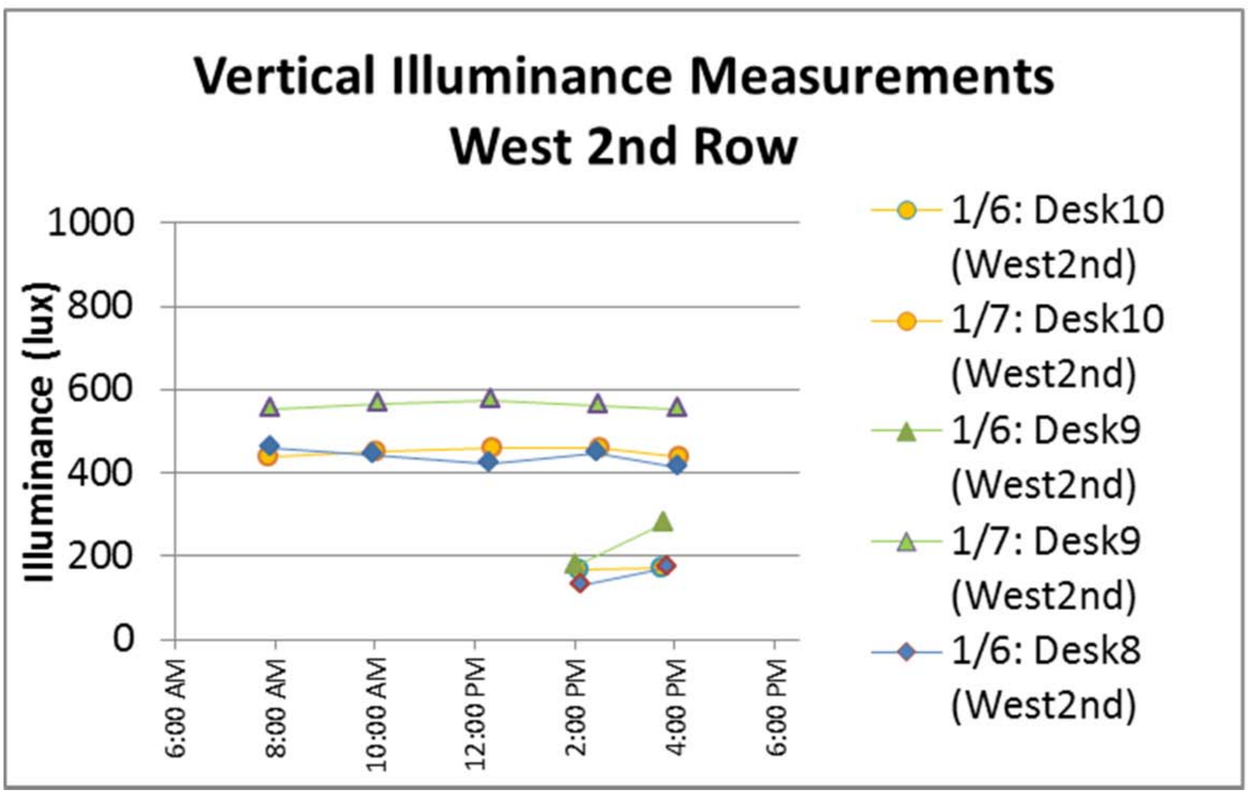
Appendix C: Photometric Measurements for West Exposure

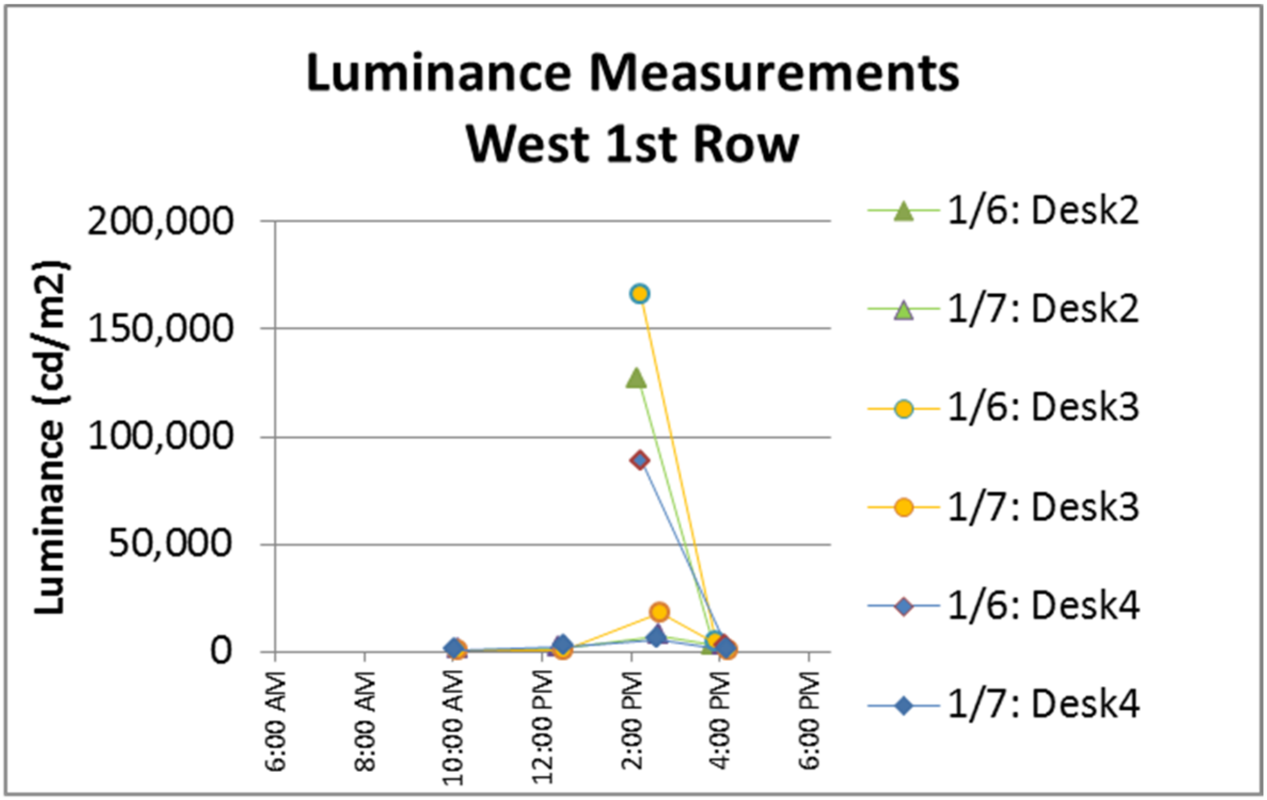
					Task Light On		Task Light Off			
	Floor	Orientation	Row	Desk	Horiz Desk (lux)	Vert Surface (lux)	Horiz Desk (lux)	Vert Surface (lux)	Notes	Luminance (cd/m2)
1/6/14 2:16 PM	1	West	1	#4			155	35	No task lts, mesh shades closed	87980
1/6/14 4:08 PM	1	West	1				127	20	No task lts, mesh shades closed	2380
1/7/14 7:47 AM	1	West	1				427	55	No task lts, mesh shades closed	N/A dark outside
1/7/14 10:05 AM	1	West	1				579	78	No task lts, mesh shades closed	520
1/7/14 12:31 PM	1	West	1				606	100	No task lts, mesh shades closed	2600
1/7/14 2:36 PM	1	West	1				593	95	No task lts, mesh shades closed	5500
1/7/14 4:11 PM	1	West	1				563	92	No task lts, mesh shades closed	770
1/6/14 2:13 PM	1	West	1	#3	488	541			Task lights on, mesh shades closed	166000
1/6/14 3:53 PM	1	West	1		496	509			Task lights on, mesh shades closed	5200
1/7/14 7:48 AM	1	West	1		860	560	558	91	Measured w/ and w/o task light	N/A dark outside
1/7/14 10:07 AM	1	West	1		912	613			Task lights on, mesh shades closed	490
1/7/14 12:28 PM	1	West	1		948	571			Task lights on, mesh shades closed	880
1/7/14 2:38 PM	1	West	1		942	580			Task lights on, mesh shades closed	18430
1/7/14 4:10 PM	1	West	1		881	572			Task lights on, mesh shades closed	830
1/6/14 2:10 PM	1	West	1	#2	401	781			Task lights on, mesh shades OPEN	126600
1/6/14 3:51 PM	1	West	1		393	789			Task lights on, mesh shades OPEN	2200
1/7/14 7:50 AM	1	West	1		631	775	464	53	Measured w/ and w/o task light	N/A dark outside
1/7/14 10:09 AM	1	West	1		694	770			Task lights on, mesh shades OPEN	1000
1/7/14 12:25 PM	1	West	1		669	810			Task lights on, mesh shades OPEN	1710
1/7/14 2:40 PM	1	West	1		1900	796			Task lights on, mesh shades OPEN	7000
1/7/14 4:07 PM	1	West	1		655	758			Task lights on, mesh shades OPEN	2030
1/6/14 2:04 PM	1	West	2	#10			167	92	No task lights, shades N/A	4362
1/6/14 3:44 PM	1	West	2				174	93	No task lights, shades N/A	2336
1/7/14 7:53 AM	1	West	2				440	228	No task lights, shades N/A	N/A dark outside
1/7/14 10:01 AM	1	West	2				453	224	No task lights, shades N/A	520
1/7/14 12:22 PM	1	West	2				459	234	No task lights, shades N/A	680
1/7/14 2:30 PM	1	West	2				459	232	No task lights, shades N/A	910
1/7/14 4:06 PM	1	West	2				440	221	No task lights, shades N/A	350
1/6/14 2:00 PM	1	West	2	#9			175	101	No task lights, shades N/A	4639
1/6/14 3:46 PM	1	West	2				276	189	West sun strikes cubicle wall, increasing illuminance	3900
1/7/14 7:54 AM	1	West	2				552	308	No task lights, shades N/A	N/A dark outside
1/7/14 10:03 AM	1	West	2				566	313	No task lights, shades N/A	370
1/7/14 12:20 PM	1	West	2				574	329	No task lights, shades N/A	540
1/7/14 2:29 PM	1	West	2				560	329	No task lights, shades N/A	753
1/7/14 4:04 PM	1	West	2				555	304	No task lights, shades N/A	580
1/6/14 2:08 PM	1	West	2	#8			132	34	No task lights, shades N/A	3001
1/6/14 3:50 PM	1	West	2				172	90	No task lights, shades N/A	(direct sun unmeasurable)
1/7/14 7:55 AM	1	West	2				460	64	No task lights, shades N/A	N/A dark outside
1/7/14 9:58 AM	1	West	2				441	90	No task lights, shades N/A	1100
1/7/14 12:17 PM	1	West	2				422	97	No task lights, shades N/A	1400
1/7/14 2:27 PM	1	West	2				447	108	No task lights, shades N/A	1010
1/7/14 4:03 PM	1	West	2				415	93	No task lights, shades N/A	560

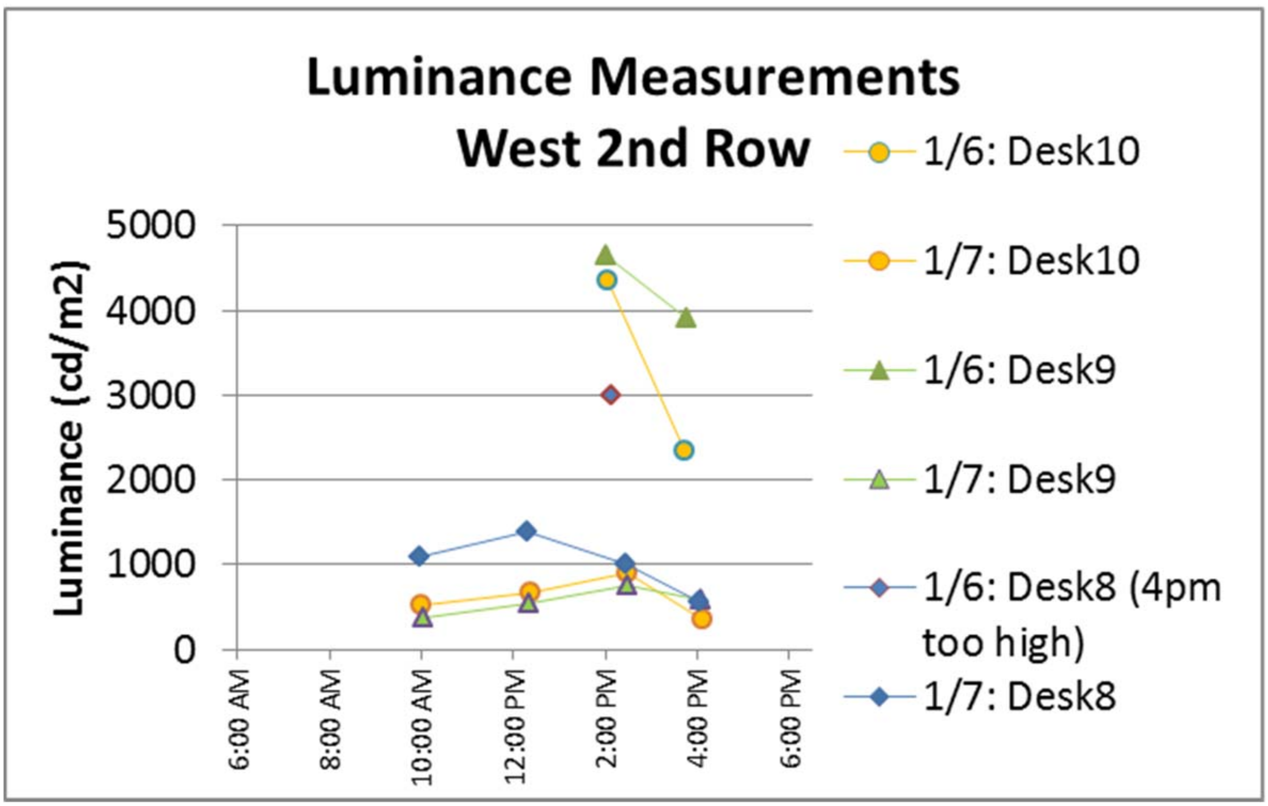

Horizontal Illuminance Measurements
West 1st Row
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Shaft of sun falls on measurement point (~1900 lx @ 2:40pm)
1/6: Desk2 (incl task, blinds open)
1/7: Desk2 (incl task, blinds open)
1/6: Desk3 (incl task, blinds closed)
1/7: Desk3 (incl task, blinds closed)
1/6: Desk4 (blinds closed, no task lt)
1/7: Desk4 (blinds closed, no task lt)


Horizontal Illuminance Measurements
West 2nd Row
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk10 (West2nd)
1/7: Desk10 (West2nd)
1/6: Desk9 (West2nd)
1/7: Desk9 (West2nd)
1/6: Desk8 (West2nd)


Vertical Illuminance Measurements
West 1st Row
1000
800
600
400
200
0
Illuminance (lux)
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk2 (incl task)
1/7: Desk2 (incl task)
1/6: Desk3 (incl task, blinds closed)
1/7: Desk3 (incl task, blinds closed)
1/6: Desk4 (blinds closed, no task lt)
1/7: Desk4 (blinds closed, no task light)

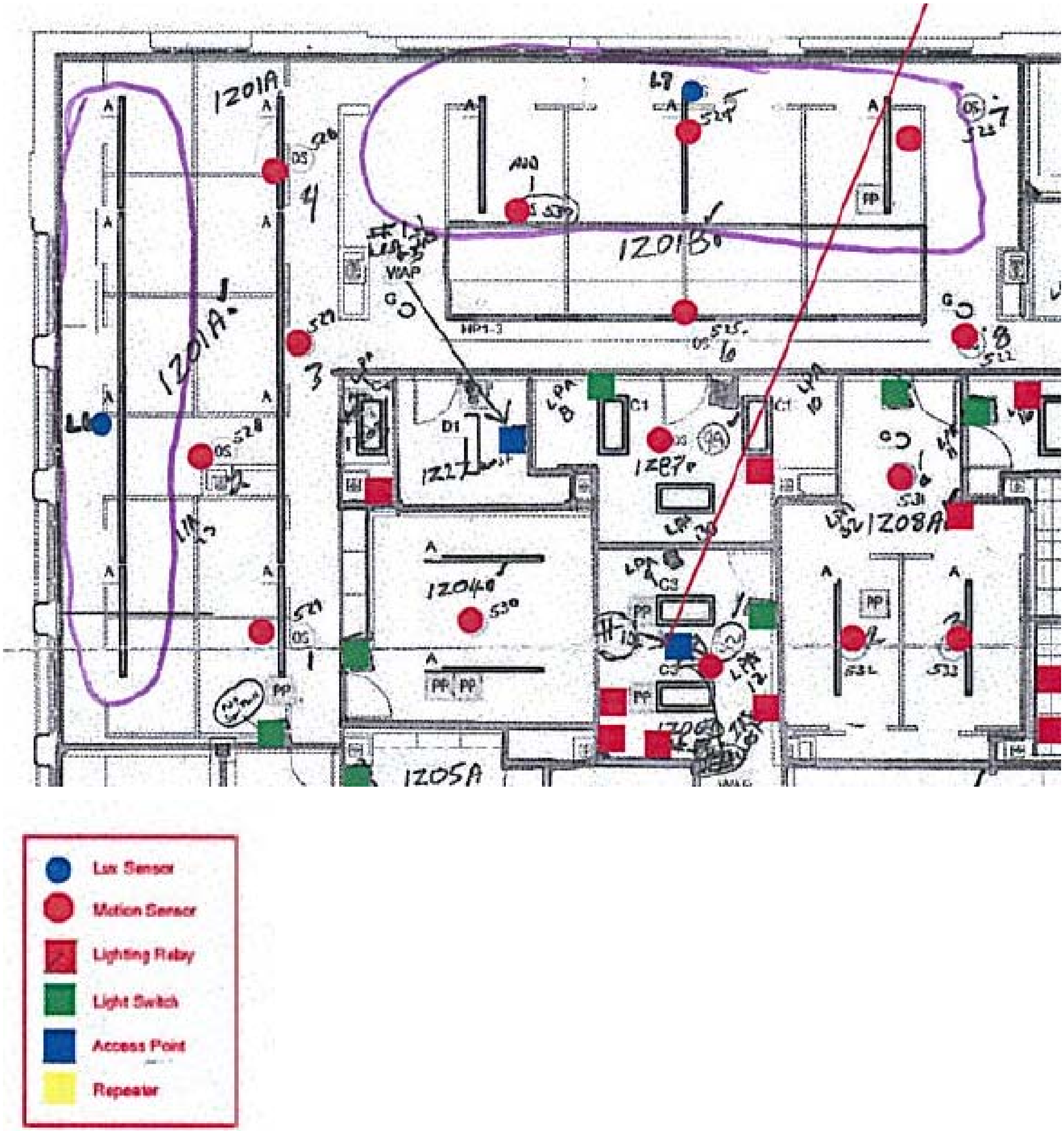

Vertical Illuminance Measurements
West 2nd Row
1000
800
600
400
200
0
Illuminance (lux)
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk10 (West2nd)
1/7: Desk10 (West2nd)
1/6: Desk9 (West2nd)
1/7: Desk9 (West2nd)
1/6: Desk8 (West2nd)


Luminance Measurements
West 1st Row
Luminance (cd/m2)
200,000
150,000
100,000
50,000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk2
1/7: Desk2
1/6: Desk3
1/7: Desk3
1/6: Desk4
1/7: Desk4


Luminance Measurements
West 2nd Row
Luminance (cd/m2)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
1/6: Desk10
1/7: Desk10
1/6: Desk9
1/7: Desk9
1/6: Desk8 (4pm too high)
1/7: Desk8

APPENDIX D: LIGHTING CONTROL PLANS

LIGHTING CONTROL PLAN, FIRST FLOOR STUDY AREA



LIGHTING CONTROL PLAN, SECOND FLOOR STUDY AREA